Navy Experimental Diving Unit
321 Bullfinch Rd.
Panama City, FL 32407-7015

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HARDWARE AND PROCEDURES FOR USING THE DIVEAIR2 MONITOR TO TEST DIVING AIR QUALITY IN THE FIELD

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Author: R. S. Lillo
J. M. Caldwell

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15. SUBJECT TERMS

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CONTENTS

INTRODUCTION

The U.S. Navy Diver's Air Sampling Program coordinates the mandatory semiannual air purity testing of compressors used to supply diver's air in the Fleet. Gas sampling kits supplied by a contract laboratory are sent to the field, where gas samples are taken and then returned to the laboratory for analysis. Results indicating pass or fail levels according to specifications for diving air in the *U.S. Navy Diving Manual*[1] are reported back to the field.

This approach is expensive, cumbersome, and potentially unreliable. Accuracy of results depends partly on gas collection procedures in the field, and these can be difficult to perform correctly even under the best conditions. Relying on a contract laboratory also introduces concerns such as ensuring data accuracy and extended time delays between the sampling and reporting of results. Consequently, the U.S. Navy is interested in having a real-time, online air quality monitor to ensure that compressors deliver safe diving air.

The benefits of an online air quality monitor for diving compressors include

1. providing continuous, credible data immediately to personnel in the field;

2. allowing immediate retesting in case of questions and problems requiring troubleshooting;

3. eliminating potential sampling problems associated with gas collection and storage for later analysis;

4. eliminating current logistical requirements associated with sampling kit delivery and return;

5. allowing initial screening of ambient air at diving sites having suspect air quality (e.g., fuel-laden salvage sites) before compressor start-ups, followed by subsequent testing of compressor discharge air; and

6. allowing commercially obtained diving air to be tested by forward-deployed personnel.

Thus, using these monitors could replace or supplement present methods that encumber the U.S. Navy Diver's Air Sampling Program. However, it is important to note that a decision about how any monitor will be used in the Fleet is the responsibility of Naval Sea Systems Command (NAVSEA 00C).

DEVELOPMENT OF THE DIVEAIR2 AND NEXT STEPS

With the help of the manufacturer, NEDU developed an online air quality monitor (Anagas Diveair2, model DV 2.0, Geotechnical Instruments, Inc.; Leamington Spa, UK) for compressors that supply diving air for U.S. Navy operations.[2] Adapted from an earlier version of the Diveair (model DV 1.1) described and evaluated in two previous reports,[3,4] this DV 2.0 compressor was designed to measure and simultaneously display levels of O_2, CO_2, CO, and volatile organic compounds (VOCs). Through an iterative process of repeated laboratory testing followed by manufacturer modifications in response to NEDU testing results, the Diveair2 prototypes initially delivered to NEDU were refined over several years to better meet requirements for air monitoring in the field. This monitor has many features designed specifically for the Navy: (1) an internal gas pump, (2) visual alarms, (3) datalogging capability, (4) a push-button program to automatically record peak gas values during testing, (5) temperature compensation of gas readings, and (6) passcode protection for calibration and other functions. The final Diveair2 version that we have tested should allow reliable real-time screening of diving air — provided that any hardware and procedures adopted for field use are verified to produce acceptable results.

Following completion of our development of the Diveair2 in 2008 and of our report published in March 2009, the Diveair2 was added to the Authorized for Navy Use (ANU) list. NAVSEA 00C then purchased 25 of the first production monitors to start transitioning the Diveair2 to the Fleet to screen diving air. The Command also developed an air sampling kit including a pressure reducer, hardware connections, and calibration gases designed for field use with the Diveair2. On a limited scale, it then began to deliver air monitors and testing kits to the Fleet for use — with certain restrictions, however.

A major issue limiting more widespread use of the monitor was its inability to screen all the constituents required by the *U.S. Navy Diving Manual* in either Table 4-1 or Table 4-2.[1] As the Diveair2 measures levels of O_2, CO_2, CO, and VOCs, this monitor could be used to determine whether diver's breathing air from the ANU or other certified diving systems meets all purity standards (except those for oil, mist, and particulates) of Table 4-1. For diver's breathing air from commercial sources, the Diveair2 does not allow screening for the following three constituents now required by Table 4-2: (1) oil, mist, and particulates; (2) total water; and (3) halogenated compounds. Consequently, NAVSEA 00C is currently reviewing diving air purity standards in the *U.S. Navy Diving Manual*, with the idea of possibly combining Tables 4-1 and 4-2 to reduce the number of components required for screening without compromising safety. Major issues are the number of differing standards for diving air and the question of what standards are most appropriate for the U.S. Navy.[5,6]

In May 2009 an initial meeting was held at NAVSEA 00C to start reviewing the tables to determine whether air purity standards can be simplified without compromising safety and whether procedures can be developed to allow field screening for all constituents of

concern. Consolidating Tables 4-1 and 4-2 would define what additional analyzers and procedures would be required to facilitate complete screening of diving air in the field.

GOAL

Through completing the following tasks, this work was to help transition the Diveair2 air quality monitor to the Fleet:

1. Conduct limited laboratory testing of a sample of first-production monitors to ensure that they operate correctly.

2. Evaluate in the laboratory the NAVSEA 00C air sampling kit's reliability in screening air, and revise the monitor and kit procedures as needed.

3. Assist in conducting a limited field test using the revised (if necessary) air sampling kit and monitor to determine (1) the need for any changes in the kit or the procedures and (2) the feasibility of relaxing the current NEDU recommendation for daily calibration in the field.

4. Since a need for water analysis may be required following any combining of Tables 4-1 and 4-2, identify and test candidate water analyzers in the laboratory, and develop procedures for their use in the field.

METHODS

NAVSEA 00C AIR SAMPLING KIT

To facilitate our testing, the U.S. Navy's Emergency Ship Salvage Material (ESSM) System (which stores the kits until NAVSEA 00C has received and approved requests for them before they are sent out to the Fleet) loaned us two complete NAVSEA 00C air sampling kits. Each kit consisted of three containers.

1. One medium-sized Pelican case containing the air sampling hardware, consisting of

    a. four high-pressure (HP) adaptors to attach to various Navy sources of diving air — scuba, the Lightweight Dive System (LWDS), and the Fly-Away Dive System (FADS);

    b. one pressure-reducing regulator ("reducer") mounted on the inside of the lid of the Pelican case, with a small button particulate filter within its upstream port and with a downstream pressure gauge 0–15 psig, to reduce air sample pressures to several psig and to deliver a low, constant air flow to the air monitor;

c. one HP microhose assembly (the “HP sampling whip”), a 10-foot long polyamide 11 (a nylon) inner hose of 2.9 mm inner diameter (ID) to connect the HP air sampling hardware to the reducer;

d. one Teflon-tipped CGA 580 calibration adaptor with handwheel, to allow the N_2 gas cylinder to be attached, during calibration of the air monitor, to the reducer via the HP sampling whip; and

e. one length (~24 inches) of Teflon tubing, with flexible polyvinyl chloride (PVC) ends to connect the monitor to the reducer via hose barb fittings.

2. One large Pelican case containing two refillable aluminum calibration gas cylinders, each having an outside diameter of ~7 inches and a height of ~16 inches and containing ~30 ft^3 of two different gases at 2000 psig:

   a. N_2 (stated as 99.95%) for zeroing the air monitor, with moisture <5.0 parts per million (ppm) and total hydrocarbons <0.5 ppm, and

   b. span gas with nominal concentrations of 21% O_2, 1000 ppm CO_2, 20 ppm CO, 10 ppm isobutylene (used to calibrate for VOCs), and balance N_2, for spanning the air monitor. These concentrations are certified standard, with analytical tolerance given as ±2.0% for all four components.

3. One small orange-colored plastic container holding

   a. one of the 25 initial production monitors that NAVSEA 00C had purchased;

   b. a battery charger;

   c. one CGA 590 calibration adaptor, Teflon-tipped but without a handwheel, to allow the span gas cylinder to be attached to the reducer via the HP sampling whip during calibration of the air monitor;

   d. one air monitor operating manual from Geotechnical Instruments; and

   e. instructions and other paperwork from NAVSEA 00C.

All the hardware adaptors and the HP sampling whip had A/N connecting fittings.

In addition to the two complete air sampling kits we originally received, we subsequently requested and received three more DiveAir2 monitors and two more sets of sampling hardware for testing.

LABORATORY TESTING

At the start of this project, we used methods described in the March 2009 report[2] to test the first production air monitors in the laboratory and confirm acceptable monitor operation before any further work was done. After we found and resolved monitor operating problems, we conducted most of the further testing with the NAVSEA 00C sampling kit to deliver the test gas to the air monitors; we later used a revised NEDU sampling kit to address weaknesses of that original kit. Those March 2009 methods[2] were adapted to evaluate the reliability of both kits and the need for any changes to the hardware or procedures; additional testing details, along with the results, are provided in the **RESULTS AND DISCUSSION** section. For all testing, we recorded gas readings from the monitor after the normal equilibration time of at least five minutes had passed.

FIELD TESTING

A limited field test using the revised NEDU air sampling kit was conducted at two sites. The initial site arranged by NAVSEA 00C was at Norfolk Naval Shipyard (NNSY); a second site was subsequently arranged at NEDU. The primary goal of the field testing was to determine the need for any changes in the new NEDU kit or in procedures; a secondary goal was to evaluate the feasibility of relaxing the current NEDU recommendation for daily calibration in the field.

To prepare for the field testing to be done at NNSY, we (1) constructed three identical NEDU air sampling kits; (2) completed initial discussions with personnel at NNSY and scheduled a start date in early December 2010; (3) wrote a Field Test document for NNSY personnel to follow during the testing; and (4) finally shipped to NNSY, during the last week of November, two of the NEDU air sampling kits, each which included one pair of calibration gas cylinders (N_2 and span gas). A copy of the Field Test document was provided to NAVSEA 00C before NNSY testing began. We also sent two digital thermometers for measuring ambient temperature and three additional pairs of calibration cylinders to NNSY in a separate shipping case, so that these cylinders would be available if the original set of gases were used up.

NNSY testing began in early December and was initially planned to continue at least several months, although we acknowledged that testing duration and any need for changes in the field test plan would depend partly on initial results. In January 2011 we started a second field test exercise at NEDU, since the third NEDU sampling kit was available and NEDU personnel were eager to assist in the testing.

Field testing entailed using the NEDU air sampling kit with its air monitor to screen for O_2, CO_2, CO, and VOCs (including hydrocarbons) from one or more of the following air sources that had been targeted by the original NAVSEA 00C kit:

1. compressors and air banks,

2. scuba bottles that had already been charged,

3. the Navy's LWDS, both during and after charging, and

4. the Navy's FADS, both during and after charging.

In addition, when time was limited or no diving air source was readily available, the monitor could be used alone to test the quality of the ambient air at various locations.

We recommended that initial testing at NNSY be done on as many work days as possible to facilitate tracking of the air monitor's calibration stability. For the purposes of this field test, we assumed that the sampling hardware of the two kits was identical. Therefore, to simplify testing, we advised that testing be initiated with only one of the kits and with the second kit held in reserve, in case problems developed with the first kit. For the first two weeks, only one monitor would be used during testing; for the second two weeks, the other monitor would be used. This approach would help answer questions about the calibration stability of the monitor. Following the first four weeks of testing, results would be reviewed, and NEDU would decide how additional testing should be done.

When testing was not being done, and whenever possible, the monitor and all test gear were to be stored inside, protected from inclement weather and maintained at temperatures ranging between 19 and 25 ºC (66–77 ºF, "normal room temperature"). Since Fleet personnel with minimal or no formal training might eventually be using the air testing procedures (or adaptations from them), the Field Test document included few additional instructions beyond the actual procedures — to allow the field-tested air sampling kit and monitor to be realistically evaluated. Although we briefly reviewed the test procedures with some NEDU participants shortly after testing had begun, no formal initial training was given to personnel doing the testing. However, to answer specific questions, two steps unique to these field test procedures were included:

1. To help in making recommendations about calibration frequency in the field, recalibration was performed only when N_2 or span gas readings before calibration exceeded predefined allowable ranges that were wider than planned for routine Fleet use.

2. To help evaluate the monitor's performance, ambient temperature — which can significantly affect gas readings — was recorded, when possible, at specific times during testing.

Under the calibration rules for field testing, the monitor was *not* zeroed if N_2 gas readings before any zeroing were all less than 0.5% O_2, 100 ppm CO_2, 5 ppm CO, and 1.0 ppm VOC. Also, the monitor was *not* spanned if span gas readings before any spanning were all within 0.5% O_2, 100 ppm CO_2, 5 ppm CO, and 1.0 ppm VOC of the span gas values. These allowable gas range readings before zeroing or spanning was required facilitated examinations of how much calibration settings "drifted" over time.

During each day's field testing, an important part of that testing was to use the monitor's "Peak Program" function to record the highest concentrations of CO_2, CO, and VOCs as well as the lowest concentration of O_2 — values which this report will subsequently refer to as "peak values." Although the monitor has a datalogging capability that was extensively used during our laboratory testing and monitor evaluation reported in March 2009, no datalogging was performed during field testing. We are unsure whether the Fleet regards datalogging as a desired function for normal air sampling.

The two-page data sheet at the end of the Field Test document was designed with the hope that, after completing several days of testing, testers might be able to conduct the tests by following the data sheet — and needing minimal help from procedures detailed in the Field Test document. We also expected that, after a little experience in using the monitor, personnel could initially check its settings and its status during start-ups and calibrations very quickly.

The first day of testing started with initial calibration; subsequent days followed with calibration checks and recalibration only if these were necessary, on the basis of the calibration "rules" discussed. However, if monitors had not been used for testing within two weeks, they were to be fully calibrated (zeroed and spanned) regardless of their precalibration gas readings. (As discussed in the **RESULTS** section, some deviations from this calibration approach occurred.)

All field-testing personnel were told that results obtained were considered to be research data — *not* data to be used to determine whether the compressor meets *Diving Manual* specifications for diving air. Thus, the standard for pass/fail assessments of diver's air during this testing period remained with the current U.S. Navy Diver's Air Sampling Program and its contract laboratory.

Aside from the two unique aspects of the field testing already noted (i.e., different calibration rules and the recording of ambient temperature), the procedures used to test diving air with the NEDU sampling kit were nearly identical to those **Appendix A** procedures currently recommended for the NEDU kit. The major exception was in the **Appendix A** calibration frequency changes discussed in the **FINAL CONCLUSIONS AND RECOMMENDATIONS** section of this report.

WATER ANALYZER TESTING

On the basis of our experience with a Vaisala hand-held humidity meter (Vaisala Oyj, Finland), we chose a Vaisala dewpoint meter (DM70) with a thin-film polymer sensor as the candidate monitor for evaluation in screening diving air for water content. The DM70 we tested consisted of a MI70 indicator (the "meter") and a DMP74B dewpoint probe. This probe was specified to have a measurement range from –70 to +30 ºC, although accurate measurements (less than ±2 ºC dewpoint) appeared feasible only down to –60 to –50 ºC over a process (or "ambient conditions") range from 20 to 30 ºC.[7]

Two separate dewpoint probes — each factory calibrated within the year, per the manufacturer's recommendation — were used for testing. As recommended for measuring low dewpoints with the DM70 when stabilization times can be one to two hours, we (1) turned off the automatic power-off function so stabilization could be monitored, (2) turned on the automatic autocalibration to ensure accurate measurements, and (3) turned on the automatic sensor purge that dries the sensor, to ensure the shortest possible response times.[7]

For testing gases with the dewpoint meter, we used two separate Vaisala DSC74A sampling cells, into which the dewpoint probes were screwed. The sampling cell was then attached, via a quick-disconnect (QD) fitting supplied with the sampling cell, to the downstream side of the reducers from several of the air sampling kits. This setup allowed HP test gas delivered to the reducer to flow from the low-pressure side of the reducer into the sample cell, from which the gas then exited via an adjustable leak on the sampling cell. Test gases included ultra zero-grade air (with a water specification of <2 ppm [equivalent dewpoint, less than –72 ºC]) and one certified gas standard (36 ppm, balance air [equivalent dewpoint, –51 ºC]). To evaluate how flow rate affects the equilibration of the dewpoint meter, we also omitted the reducer in delivering low-pressure (<1 psig) gas directly to the sampling cell with a rotameter flow meter inserted between the gas source and the sampling cell. This setup allow the flow rate to be manually varied, with the accuracy of flow rates displayed by the rotameter previously checked by collection of gas in water-filled graduated cylinders.

RESULTS AND DISCUSSION

LABORATORY TESTING OF AIR MONITORS

Testing of three of the first production air monitors revealed that two displayed some operating problems over a several-month period. As needs for repairs arose, these monitors were returned to the UK manufacturer, a time when their recommended 18-month servicing (which was coming due) was also completed. At our convenience, the third monitor (with no operating problems) was also returned for servicing. To facilitate our testing when one or more of the first three monitors was being repaired or serviced, we requested and received from ESSM two additional monitors, both of which also demonstrated problems during our testing and thus had to be returned for repair and servicing. In some cases we had to return monitors to the manufacturer more than once to restore normal operation. The problems with the particular monitors included the following.

First three monitors tested:

Monitor #311: unstable O_2 and CO readings; LCD display failed

Monitor #312: low O_2 gases (e.g., 10% O_2) read incorrectly
Monitor #322: [no problems detected]

Second two monitors tested:

Monitor #315: photoionization detector (PID) sensor failed; CO_2 calibration problems

Monitor #324: LCD display and keyboard locked up

This record of failures with the Diveair2 was unexpected following the relatively low incidence of instrument failures during its development as reported in the March 2009 report.[2] However, we suspect that many, if not most, of these problems may have resulted from shocks that they had sustained during shipping: The lightweight plastic case that housed each monitor (as discussed below in the **REVIEW OF THE NAVSEA 00C AIR SAMPLING KIT** section) protected them poorly. Another factor contributing to the monitor problems may have been their storage at ESSM without apparent regular use for long time periods: Such storage is generally acknowledged to be unfavorable for maintaining good working condition in electrical instruments.

From our limited laboratory testing of the first production monitors (after these problems had been discovered and repaired), we provide accuracy data here. Due to the number of unexpected problems with these monitors, most of them were tested at 25 ºC, the same room temperature exposure we had used extensively for testing during the Diveair2's development. Testing at 25 ºC was deemed most suitable initially to verify that those first production monitors were operating correctly and then (following any necessary repairs) to confirm that they were free of those initial problems. Because of the number of problems we encountered, we spent most of the testing time returning the monitors to acceptable operating status and completing the recommended 18-month servicing before we could proceed with this project's additional tasks. The five monitors were subjected to a varying number of 25 ºC tests, since up to three of them were tested together on any given day, and the specific ones being tested varied with both the NEDU monitor population and operating status on that day. To briefly check how well the first production monitors compensated for changes in ambient temperature, several tests with three of them were finally conducted at 42 ºC and 5 ºC.

We compare the new data from the first production monitors with that from the final version prototypes.[2] Following the repackaging of this final version prototype into an increasingly rugged Pelican case providing improved protection and transport, this final version prototype was designated as the "final reboxed monitor."[2] However, for discussion here, we will simply refer to this monitor as the "final prototype." To facilitate comparison with the final prototype data, we have plotted the new data on graphs with *x*- and *y*-axes identical to those for the final prototype except where there is greater spread in the data from the first production monitors. Where there are important differences between the new data and that of the final prototype, we have included the respective final prototype graphs taken from the final report on the Diveair2.[2]
As reported,[2] the measurement error (based on chamber testing at 25 ºC immediately following calibration) for the final prototype was, on average,

for O_2: ±0.2% absolute across the test range of 0 to 21%, but ±0.1% O_2 at the span value of 21%;

for CO_2: ±40 ppm across the test range of 0 to 1000 ppm, but ±30 ppm at the span value of 1000 ppm;

for CO: ≤2 ppm low across the test range of 0 to 20 ppm; and

for VOCs: ≤0.4 ppm low across the test range of 0 to 10 ppm.

As the 25 ºC accuracy plots for the first production monitors show (Figs. 1–4, "A" graphs only), the measurement errors for those monitors can also be described in similar terms. As was the case with the final prototypes, the current test results generally show good consistency both among analyzers (note the overlap of their plots) and consistency over test days (shown by the generally small standard deviations). The only exception to this latter statement is that of first production monitor #311 for O_2 and CO_2, as both these plots have standard deviations larger than those of the final prototypes — an unexplained result of higher-than-expected O_2 and CO_2 readings during one of its five test days.

We judged the monitors' short-term variability by the difference between two repeated accuracy tests at 25 ºC: (1) The first test (discussed in the preceding paragraph) was performed in the morning immediately following calibration, and (2) a second and identical 25 ºC test was conducted in the afternoon, with no recalibration between the two tests. This measurement found the short-term variability of the five first production monitors to be low (Figs. 5A–D), at a level very similar to that for the final prototypes shown in the March 2009 report[2] and suggesting excellent short-term calibration stability. That report found short-term variability of the final prototypes to be, on average,

for O_2: ±0.1% absolute,
for CO_2: ±20 ppm,
for CO: ±1 ppm, and
for VOCs: ±0.1 ppm.

Among the first production monitors, the only significant exception from the final prototype results is in monitor #311, which shows a slightly greater variability between morning and afternoon measurements for O_2 and CO_2 — results slightly higher than expected O_2 and CO_2 readings during a single morning test.

Figures 1–4 (A–C) present test results from the first production monitors and from past testing with the final prototypes at three test temperatures. Again, the 25 ºC tests were in the morning and immediately after calibration, with second tests in the afternoon at either 5 or 42 ºC. Past testing, as reported in the March 2009 report,[2] showed that ambient temperatures affected the final prototype readings, on average, as follows:

1. Whereas the O_2 error was ±0.2% absolute at 25 ºC across the test range of 0 to 21%, O_2 readings were ≤1% low at 42 ºC and ≤1% high at 5 ºC. These results are *similar* to the temperature responses for the first production monitors.

2. Whereas the CO_2 error was ±40 ppm at 25 ºC across the test range of 0 to 1000 ppm, CO_2 readings were ≤100 ppm low at 42 ºC and ≤100 ppm high at 5 ºC. As can be seen by comparing the two new graphs 2B–2C to the two graphs 2D–2E from the final prototypes, these results *contrast* with those from the first production monitors, with CO_2 readings ≤200 ppm low at 42 ºC and ≤100 ppm low at 5 ºC.

3. Whereas CO readings were ≤2 ppm low at 25 ºC across the test range of 0 to 20 ppm, these readings were ≤3 ppm high at 42 ºC and ≤4 ppm low at 5 ºC. These results are *similar* to the temperature responses by the first production monitors.

4. Whereas VOC readings were ≤0.4 ppm low at 25 ºC across the test range of 0 to 10 ppm for the three final prototypes, this error was ±0.5 ppm at 42 and 5 ºC for the two final prototype monitors, which received temperature corrections for the PID specific to each sensor. However, this relatively low VOC error contrasts with the considerably greater error at 42 and 5 ºC for a third prototype monitor, which received the same temperature correction that had been developed for one of the other two monitors. As can be seen by comparing the two new graphs 4B–4C to the two graphs 4D–4E from the final prototypes, the results for the two prototypes with their own temperature correction (monitors #298 and #299) *contrast* with those from three of the first production monitors, with VOC readings ≤3 ppm low at 42 ºC and a VOC error of ±0.4 ppm low at 5 ºC.

Conclusions

1. After the first production monitors had received required repairs to correct any apparent operating problems, limited laboratory testing suggested that their gas monitoring performance was similar to that of the final prototypes, as the March 2009 report documented.[2]

2. The only significant performance difference between the first production monitors and the final prototypes was the greater VOC error at 42 ºC by the first production monitors. In view of the March 2009 findings[2] that suggested each PID sensor required its own temperature compensation, these results raise the question of whether the PIDs in the first production monitors were individually compensated for temperature.

3. The reason(s) for the many initial problems with the first production monitors cannot be definitively known — although the factors of their shipping and storage for long periods without apparent regular use appear to be likely possibilities.

4. The record of failures with the first production Diveair2 monitors suggests that, until proven otherwise, these monitors should be used with caution.

REVIEW OF THE NAVSEA 00C AIR SAMPLING KIT

The two complete NAVSEA 00C air sampling kits were delivered to NEDU together on one shipping pallet and bound with strapping bands. Unfortunately, one of the medium-size Pelican cases containing the sampling hardware had come loose from its strapping band, so that the case was left loose on the pallet.

Listed below are some of our observations and comments about the kit following an initial review.

1. Volume and weight.

The total volume and weight of the equipment are excessive. The two large cylinders of calibration gas in each kit provide adequate gas for probably at least several years of active use. Although such a gas supply might be nice to have, this amount is really not suited for a portable kit designed to be routinely sent to various sites for screening diving air. The weight and volume of the large Pelican case holding the two cylinders make its shipping to and handling at the site where it is to be used additionally difficult. The medium-size case containing the sampling hardware also wastes a lot of space by using a hard foam insert to hold the five hardware adaptors: The latter require a relatively small volume relative to the foam.

2. Packing and protection from damage.

The gas cylinders are well packed and cushioned in their case. Likewise, the sampling hardware is well protected in its own case. However, the expensive Diveair2 (along with its battery charger, CGA 590 calibration adaptor, operating manual, and other paperwork) is loosely packed with sheets of bubble wrap inside the lightweight orange case, and it rattles about (actually bounces around inside) the case when the case is gently shaken. Thus, the orange case provides little, if any, protection from damage for the monitor during normal shipping procedures that might be expected to include the case being moderately impacted or being dropped. In addition, the monitor is not protected from damage from the metal CGA 590 adaptor or from the battery charger, with its metal prongs. The lack of protection for the monitor is surprising since, of all the components of the air sampling kit, we think that the air monitor — although it is expected to be able to take some abuse in the field — should be the best protected by its packing.

Along with its three alternative plug adaptors, the battery charger is packed in the same orange case as the air monitor. These adaptors allow the charger to be plugged into other power sources (e.g., those of the UK, Europe, Australia). Although a small cardboard box houses the charger and adaptors, this box (if it is used, since we found

that charger parts in some of the kits we received were loose in the orange case) provides little protection and had fallen apart in some of the kits.

In all the air sampling kits we examined, the air reducer mounted inside the lid of the hardware case was open to the atmosphere at its low-pressure outlet, and the Teflon tubing used to connect the monitor to the reducer sat loose, open at both ends, in the bottom of the hardware case. Thus, both the reducer and tubing are vulnerable to possible contamination.

3. Sampling procedures.

Operating guidance provided to users of the NAVSEA 00C sampling kit consists of both hardcopy material accompanying the Navy sampling kit and information with videos on the NAVSEA 00C website.

The following guidance comes with the sampling kit:

a. Hard copy of the Diveair2 Operating Manual from Geotechnical Instruments, Inc.[8]

b. NAVSEA 00C letter of 6 March 2009,[9] providing instructions for using the monitor.

c. Geotechnical Instruments' certificate of calibration for the Diveair2.

d. Certification testing paperwork for calibration of the CGA 590 adaptor (in the bag with the adaptor).

The following guidance can be accessed on the NAVSEA 00C website:

a. PDF copy of the operating manual (apparently identical to the hard copy provided with testing kit).

b. Air-Quality Test Log (one-page sheet to record monitor readings).

c. PAM Introduction Video, produced by Geotechnical Instruments, Inc., which calls this an "Interim Service" video.

d. PAM Verification Video, produced by Geotechnical Instruments, Inc.

Conclusions

After reviewing the operating procedures information provided with the kit and on the NAVSEA 00C website, we make the following conclusions. Some suggestions — which were proposed as interim steps until a complete set of recommendations could be

provided — were sent previously to NAVSEA 00C and are included here. Following laboratory testing of the NAVSEA 00C air sampling kit (next section), additional suggestions are also made.

1. Packaging.

The current NAVSEA 00C air sampling kit incorporates a large volume of equipment. All this packaging makes its shipping and field use cumbersome, and it still provides poor protection for the Diveair2 monitor and some of the other testing components. The current NAVSEA 00C air sampling kit should be reduced: from three cases including two large calibration gas cylinders, to a new version kit containing one medium storage case with smaller calibration gas cylinders and improving its protection for the air monitor and other hardware.

2. Operating procedures.

No specific procedures on how to use the air monitor and testing kit to reliably sample diving air are provided to the user. The Operating Manual is a good reference, but it does not refer to the Navy's sampling kit and therefore does not provide the procedures necessary to ensure that the user has sampled air correctly. In addition, important details — such as how ambient temperature can be expected to affect gas readings and how the monitor is not to be operated while it is connected to the charger (since the charging process can affect gas readings) — are not addressed.

Our years of experience in providing procedures to the Fleet suggest that the best way to present such information is usually to have one document giving users step-by-step instructions to follow — rather than to require them to consult multiple sources for guidance, or merely to provide them with an operating manual for help. But the latter two means are employed by the NAVSEA 00C kit.

3. The Diveair2 calibration certificates.

These documents provide no useful information other than to confirm that a monitor has been successfully serviced by Geotechnical Instruments, a status which is assumed when ESSM provides the user with the monitor.

4. The two videos on the NAVSEA 00C website.

These provide minimal important information, and it can be given more effectively and quickly by written instruction. Geotechnical Instruments calls the first "Introduction" video (more than two minutes long) an "Interim Service" video, but it provides little information beyond battery testing. The second "Verification" video steps the users through calibration but requires them to adjust the flow from a small-calibration bottle to 300 mL. Since the Navy will be using an entirely different system for delivering gas via the reducer, this video is more confusing than helpful.

5. The NAVSEA 00C letter which is included in the kit.

This letter states that the data log sheet provided on the NAVSEA 00C website is "an example" for recording results. This statement seems to allow or invite the use of an unlimited number of different log sheets.

LABORATORY TESTING OF THE NAVSEA 00C AIR SAMPLING KIT

1. Reducer flow rates.

The flow rates below were measured from the low-pressure side of the reducers from the first three air sampling kits listed (#11, #12, and #22) when pressurized gas was delivered to the HP side of the reducer from a calibration cylinder of N_2 or span gas at cylinder pressures from 500 to 2600 psig. The reducer from kit #21 was used in the later testing of the dewpoint meter, and its flow (2000 psig) was measured in a similar manner with a cylinder of dry air.

Reducer Flow Rates (mL/min)

	N_2	Span Gas
Kit #11	**150–160**	**150–160**
Kit #12	**130–135**	**120–135**
Kit #22	**130–135**	**130–145**
Kit #21 (used for water testing)	**110–115 (Air)**	

These ranges in reducer flow are based on repeated measurements from the first three reducers over a period of 11 days (or from #21 over a period of a week) made to the nearest 5 mL/min at room temperatures of 21–25 ºC, measurements using a 65 mm, 20–250 mL/min direct reading rotameter (model PMR1-010854; Cole-Parmer, Vernon Hills, IL) calibrated by the manufacturer in “STP mL/min air at 70 ºF @ 1 ATM” (standard temperature pressure at 1 atmosphere absolute). Although the rotameter was calibrated to read directly with air, the manufacturer affirmed its accuracy to be ±5% of full scale (with a 0.25% repeatability of reading) — an accuracy that, by separately measuring the volume of each gas collected downstream from the rotameter in an initially water-filled, inverted graduated cylinder, our laboratory confirmed several times for both span gas and N_2 at flow rates of ~150 mL/min. Thus, any small differences in rotameter measurements of span gas and N_2 that were due to the effect of gas density (the density of span gas being essentially equivalent to that of air, and the density of N_2 being slightly less than air) were within the rotameter’s accuracy range.

When a regulator on the span gas and N_2 bottles was used to deliver gas to the reducer at lower pressures (20 to 50 psig), reducer flows for the four air sampling kits were observed to be within the measurement accuracy of the flows with the higher pressures as reported above in this section. However, flows declined dramatically when delivery pressures were decreased to ≤5 psig.

Over the range in pressures delivered to the reducer, the downstream reducer gauge read ~2.0 to ~3.5 psig, with the full range of the gauge being 15 psi.

2. Effect of flow rate on gas readings.

When gas flow measured with the rotameter and directly delivered to the monitor without the reducer in line was varied multiple times back and forth from 200 mL/min to 50 mL/min, no difference could be observed in monitor gas readings when span gas or N_2 was sampled. After each change in flow rate, at least 5 min was allowed for readings to stabilize before they were recorded. This testing was completed for three monitors (#312, #315, and #322) on one test day.

3. Comparison between gas delivery with the sampling kit's hardware and open-split gas delivery with the sampling pump on.

Throughout one week, multiple tests with three monitors when the kit hardware was used showed little difference in gas readings from those when using the open-split gas delivery method, the latter having been employed nearly exclusively during development of the monitor.[2] The only apparent difference was that VOC readings for the span gas were up to 0.3 ppm lower for the kit hardware than for the open-split method for reducer delivery pressures from 20 psi to 700 psig. In testing with and without the whip held at ~20 psig via a bottle regulator, the whip sometimes introduced VOCs up to 0.8 ppm into the N_2 or the span gas, a result apparently due to memory from prior span gas exposures. When the HP whip was directly attached to gas bottle, and thus under the much higher dilutional pressures (>600 psig) of the gas bottles, we observed negligible effects on the gas readings for span gas and N_2.

4. Effect of stopping gas flow.

Span gas or N_2 was delivered to the reducer at low pressure (≤20 psig) with the monitor connected downstream. By closing the delivery valve at the gas bottle regulator and then immediately disconnecting the delivery line from the regulator, we were able to record gas readings after the normal equilibration time of at least five minutes and compare them to subsequent readings up to 10 min after the flow had stopped.

Multiple tests with three monitors on one test day showed that, after 10 min of no flow, monitor readings showed the following changes:

Span gas: O_2 values decreased up to 0.5% absolute.
CO_2 values decreased to 2–3 ppm.
VOCs decreased ~50% from the initial span gas reading.

N_2: O_2 increased up to 2.0% absolute.
VOCs increased up to 1.5 ppm.

5. Pump on or off while using the reducer.

In two monitors tested several times on one test day, unplanned testing of how having the sampling pump turned on while gas was being delivered to the monitor via the kit hardware might affect gas readings showed no effect on readings of span gas or N_2.

6. HP sampling whip.

The HP sampling whip used to connect the air sampling hardware to the reducer introduces ~20 mL of dead space volume into the sampling pathway. At ~3000 psig, the equivalent of 4 L of gas measured at 1 atmosphere absolute (ATA) would occupy the whip and require nearly 30 min to be flushed out at an expected reducer flow rate of ~150 mL/min. Thus, the HP whip used at 3000 psig effectively introduces an ~30 min delay between the time when gas enters the upstream end of the whip and the time when the same gas leaves the whip and enters the reducer. Although lower sampling pressures would produce smaller time delays, such delays at expected sampling pressures are unacceptable for real-time air quality monitoring.

7. Measuring pressure of calibration cylinders.

To determine how much calibration gas is left, no pressure gauge is provided to measure the pressures of the two calibration gas cylinders.

8. Calibration gas adapters.

Only one of the calibration gas adaptors (CGA 580) has a handwheel that facilitates its attachment to the N_2 gas; the CGA 590 adaptor lacks such a handwheel.

Conclusions

1. The hardware in the NAVSEA 00C air sampling kit appears chemically acceptable for sampling diving air with the Diveair2 monitor. In particular, the reducer, HP sampling whip with its nylon inner hose, and Teflon tubing (to connect the monitor to the reducer) were found to allow a low flow delivery of sample gas to the monitor without significant compromise to the constituents of the span gas. This hardware produces gas readings very close to those observed with the open-split delivery method used during the original development of the monitor.

2. The VOC “memory” occasionally seen with the HP whip when that device is used at very low delivery pressures should not cause problems with its use at higher pressures — or when the whip is adequately purged (a capability here recommended as Conclusion #3).

3. The HP sampling whip introduces an unacceptable dead space between the sample site and the reducer, a dead space creating a long delay between the time when the gas enters the sampling hardware and that when it reaches the air monitor. Such a delay prevents real-time air monitoring. A method for purging the HP whip during air monitoring should be developed and included in any new version of the air sampling kit.

4. Some variation in flow rates is evident among the four reducers tested. However, results showed that gas readings with the monitor were little affected over a much larger range of flow rates than that observed among the reducers. The small variation in flow rates for each reducer seen over the testing period was within the accuracy specification of the rotameter used for measuring flow.

5. Stopping the gas flow to the monitor very substantially affects the accuracy of gas readings. The small-button particulate filter within the upstream port of the reducer is designed to reduce the chances that the orifice-based reducer will become blocked. Although the reducer's downstream pressure gauge is not meant to provide accurate, precise readings and has been observed to experience shifts in the zero pressure position of the gauge needle, this gauge shows slight pressure increases (~0.5 psig) when the reducer outlet is manually blocked. Thus, a quick manual blockage test just before the monitor is used may help confirm the presence of reducer flow.

6. To allow the status of calibration cylinders to be checked, a pressure gauge should be provided in any new version of the air sampling kit.

7. To facilitate the attachment of the CGA 590 calibration gas adaptor to the span gas, a handwheel should be installed on it.

THE NEDU AIR SAMPLING KIT (designated as version 1.0 ASK)

On the basis of recommendations sent to NAVSEA 00C early in this project (and with that Command's approval), we developed a new NEDU air sampling kit to address the weaknesses of the original NAVSEA 00C kit. Adapted from the original kit, with its cumbersome three storage cases and two large calibration gas cylinders, the NEDU kit consists of a single medium-sized storage/shipping case containing all the equipment necessary for calibrating the monitor and using it in air testing. The NEDU kit provides increased protection for the monitor, contains smaller cylinders of N_2 and span gas, and is designed to be shipped by air via FedEx or military transport.

To minimize the costs of modifying the existing NAVSEA 00C kits (if a decision were made to do so), our approach in developing a new air sampling kit was to change that original sampling hardware as little as possible. This approach drove the first decision not to change the A/N fitting framework of the NAVSEA 00C kit — although many Navy divers with whom we talked favored quick-disconnect (QD) fittings for their ease of use (more about this opinion will be given in **FIELD TESTING OF THE NEDU AIR SAMPLING KIT**, below). Consequently, following our evaluation that the NAVSEA 00C

air sampling kit's hardware was acceptable for sampling diving air, we used all the existing hardware from the original kit to make the NEDU kit — except for that existing kit's two large calibration cylinders, which we found it necessary to replace with smaller cylinders. As the preceding section on the laboratory testing of the NAVSEA 00C kit recounts, we also added some new hardware that we felt was required.

Such new hardware in the NEDU kit includes: (1) one gas "bleeder" assembly and connecting hardware that permanently attach to the existing reducer to allow the upstream sampling dead space to be purged, so that real-time air monitoring can be achieved; (2) one 0 to 3000 psig pressure gauge (and connecting hardware) for measuring pressures of the two calibration gas cylinders, to determine how much calibration gas is left; and (3) one handwheel and a longer Teflon-tipped nipple (3½ inches rather than 2½ inches, to accommodate the handwheel) installed on the existing CGA 590 calibration adaptor, to facilitate attaching the CGA adaptor to the span gas.

Draft procedures for the new kit were initially written for use during the planned field testing conducted at NNSY and NEDU.

Sampling components of the NEDU air sampling kit

Most of the sampling components of the NEDU air sampling kit described below are repeated from the earlier discussion of the NAVSEA 00C sampling kit, but they are being reiterated here to provide a complete description of this new kit. The new hardware items added to the NEDU kit are noted as "NEW." We also provide additional details about *all* the hardware, since we expect that the NEDU air sampling kit and its procedures will be those that the diving Navy will be using.

1. Two NEW calibration gas cylinders. Each is a refillable aluminum HP cylinder with an outside diameter of ~4.5 inches and a height of ~15 inches. When full, each cylinder contains ~115 L of gas at ~2000 psig:

   a. One cylinder of ultra high-purity N_2 (99.999% N_2, CO+CO_2 <1 ppm, moisture <1 ppm, O_2 <1 ppm, total hydrocarbons <0.5 ppm) for zeroing the monitor's four sensors during calibration. This cylinder replaces that having 99.95% N_2 in the original NAVSEA 00C kit.

   b. One cylinder of a certified standard with nominal concentrations of 21% O_2, 1000 ppm CO_2, 20 ppm CO, and 10 ppm isobutylene (used to calibrate for VOCs), and balance N_2 for spanning the sensors (i.e., "span gas"). Analytical uncertainties are stated as ±2% relative for O_2 and CO_2, and ±5% for CO and isobutylene. (Note: The 10 ppm isobutylene gas is nontoxic and has a long history of safe use.) This cylinder has the same nominal gas mixture as the certified standard in the NAVSEA 00C kit (with ±2.0% analytical tolerance for the four components) and replaces that cylinder.

2. One Diveair2 air monitor, with battery charger.

3. One pressure-reducing regulator (“reducer”) to reduce air sample pressures down to several psig and to deliver ~150 mL/min of air to the air monitor. This reducer includes (1) the NEW “bleeder” valve on its HP side to allow the upstream dead space to be purged, so that real-time air monitoring can be achieved, and (2) a 0–15 psi downstream pressure gauge, to confirm that gas is being delivered to the reducer. The upstream fitting is a ¼-inch male A/N allowing the HP sampling whip (component #4) to be attached. The downstream fitting is a hose barb allowing the regulator to be attached to the air monitor via Teflon tubing (component #5).

4. One HP microhose assembly (“HP sampling whip”) to connect the air sampling hardware to the reducer. The 2.9 mm ID of the 10 ft long sampling whip introduces ~20 mL of dead space volume into the sampling pathway. Made of polyamide 11 (a nylon), the inner hose has ¼-inch female A/N fittings at both ends of the whip.

5. Teflon tubing with flexible PVC tubing ends connecting the air monitor to the reducer via hose barb fittings. Teflon, which should ensure that the gas delivery system minimally affects the gas flowing through it, should be the only tubing used for this purpose. This tubing arrangement allows both calibration and sample gases to be delivered to the monitor.

6. Four HP sampling adaptors, all with downstream ¼-inch male A/N fittings to allow the HP sampling whip to be attached:

a. A scuba adaptor, to allow sampling air from scuba bottles that have already been charged.

b. A scuba-charging adaptor, to allow air from the charging whip to be sampled at the site where the charging whip attaches to that scuba bottle.

c. A LWDS adaptor, to allow air from the LWDS to be sampled both during and after charging of the LWDS.

d. A FADS adaptor, to allow air from the FADS to be sampled both during and after charging of the FADS.

7. A CGA 580 calibration adaptor, Teflon-tipped and with a handwheel and a downstream ¼-inch male A/N fitting, to allow the N_2 gas cylinder to be attached, during calibration of the air monitor, to the reducer via the HP sampling whip.

8. A CGA 590 calibration adaptor, Teflon-tipped and with a handwheel (handwheel is NEW) and a downstream ¼-inch male A/N fitting, to allow the span gas cylinder to be attached, during calibration of the air monitor, to the reducer via the HP sampling whip.

9. A <u>NEW</u> 0–3000 psig pressure gauge with a ¼-inch female AN fitting. This gauge attaches to the CGA 580 and CGA 590 calibration adaptors to measure pressures of the two calibration gas cylinders and determine how much calibration gas remains.

10. <u>NEW</u> shipping instructions and required supporting documents, to facilitate shipping the air sampling kit by air.

11. A <u>NEW</u> testing procedures document, for users of the NEDU air sampling kit.

Photos of our kit have been previously provided to NAVSEA 00C and are included in **Appendix B** of this report. Details of the new hardware items in the NEDU kit are included in **Appendix C**. Shipping procedures for the new kit are given in **Appendix D.**

NEDU sampling apparatus

Stored in the top portion of the case housing the NEDU air sampling kit, the "sampling apparatus" is used to calibrate the air monitor and sample the diving air. Mounted on a plastic panel for ease of use and transport during calibration and air sampling, this apparatus includes the following components: the reducer, the two calibration gas bottles, and the air monitor with attached Teflon tubing connected to the reducer. Leaving the Teflon tubing connected in this way during storage and shipping prevents possible contamination of both the reducer and tubing. The remaining sampling kit hardware (components #4 and #6–#9 in the immediately preceding subsection, and the battery charger for the air monitor) is stored in the bottom portion of the case, separated from the sampling apparatus by a layer of foam padding. Each of the components #6–#9 are kept when not used inside individual plastic storage bags. Required shipping documents and testing procedures (components #10–#11) are in an envelope stored under the foam padding lining the top cover of the case. When servicing is necessary, the calibration gas cylinders can be easily removed from the sampling apparatus and replaced, and the monitor can be removed quickly to allow its battery to be recharged or its data to be downloaded (if desired) at a convenient site.

To start up and calibrate the air monitor, the sampling apparatus is removed from the kit and laid horizontally on a workbench or equivalent site so that the required procedures can be easily completed. When these initial steps have been completed, the apparatus and kit are moved to the sampling location, where the apparatus is laid horizontally or set upright (as desired) and attached to the air source to be sampled with the appropriate kit hardware from the kit.

Based in part on laboratory testing of the NEDU sampling kit (as described in the section **LABORATORY TESTING AND REVIEW OF THE NEDU AIR SAMPLING KIT** directly below), draft procedures for the new kit were initially written and then evaluated during the field testing conducted at NNSY and NEDU. Final procedures for the NEDU air sampling kit (designated version 1.0 OP-ASK) are included in **Appendix A** of this report and reflect results from our testing and user input.

LABORATORY TESTING AND REVIEW OF THE NEDU AIR SAMPLING KIT

Before finalizing our draft procedures for the NEDU kit so that it could be field-tested, we tested the procedures in the laboratory for reliability and ease of use, and we discussed the procedures and kit hardware with Navy personnel at both NEDU and the Navy Diving and Salvage Training Center (NDSTC). Our discussions and testing experience demonstrated needs for some changes in both the written procedures and the two-page data sheet, changes that were made before field testing was begun. The hardware — particularly the LWDS and FADS adaptors, which we had no experience in using — was judged to be adequate for meeting the air sampling requirements.

FIELD TESTING OF THE NEDU AIR SAMPLING KIT

NNSY Testing

At NNSY, testing was done during a nearly four-month period from December 2010 to April 2011, with monitor #322 paired with air sampling kit #22, and monitor #324 with kit #12. This report separates the testing into three series for discussion here and includes some of the NNSY personnel's wording from their original test summary, where that wording seems to improve an understanding of how things were done. Although we are aware that additional testing was done (particularly during Series 1, when divers were learning the procedures), test results below are reported only from the completed data sheets provided to us. A complete summary of the peak gas readings (again, the highest CO_2, CO, and VOC concentrations, and the lowest O_2 concentration during air testing) is provided in Table 1, along with the NEDU results. The NNSY data are also individually given for each test series in the discussion below.

<u>Series 1. December 2010 to January 2011</u>.

1. One diver completed calibration indoors at a controlled temperature at NNSY's "Hyperbaric Chamber and Helmet and Dress" facility.
2. Three divers performed most air testing on scuba bottles and ambient air inside this facility.
3. However, the last day of testing was completed by BRAVO team divers on BRAVO Trailer, a 25-foot enclosed trailer with a LWDS inside it. The trailer, which does not have environmental controls, was at pierside when the BRAVO LWDS was tested.

Following calibration at 21 ºC, monitor #322 was used to sample air on five test days throughout a nine-day period. Except for one day, all testing was made at ambient temperatures of 21–22 ºC measured at the start of air monitoring; the exception was for the testing of the LWDS done on BRAVO Trailer at 3 ºC. Peak gas values ranged as follows: 21.0–21.8% O_2, 330–600 ppm CO_2, 0 ppm CO, and 0.0–0.6 ppm VOCs (Table 2). <u>These peak values are well within both Table 4-1 limits for O_2, CO_2, and CO and the NEDU-recommended limit of 10 ppm for VOCs measured with the Diveair2</u>. A

calibration check at 20 ºC on the last test day confirmed close agreement with expected readings.

Although monitor #324 did not require zeroing or spanning, we are unsure when its last actual calibration was done. Approximately one month following a calibration check of this monitor at 20 ºC, however, air was sampled on one day from the LWDS on BRAVO Trailer at 3 ºC. Peak gas values were reported as follows: 21.6% O_2, 370 ppm CO_2, 0 ppm CO, and 0.0 ppm VOCs. These peak values are well within both Table 4-1 limits and the recommended 10 ppm VOC limit. No other results for monitor #324 were reported on data sheets provided to us.

Series 2. February 2011.

1. One of three designated divers completed all calibration inside the controlled-temperature “Hyperbaric Chamber and Helmet and Dress” facility.
2. Three divers completed air testing on scuba bottles, a K220 Bauer compressor, and ambient air inside this facility.

Following calibration at 21–22 ºC, both monitors were used to sample air on the same five test days during an eight-day period. All testing was done at ambient temperatures of 19–22 ºC measured at the start of air monitoring. Peak gas values ranged as follows: 21.1–21.7% O_2, 290–1030 ppm CO_2, 0 ppm CO, and 0.0–0.4 ppm VOCs. The one CO_2 value >1000 ppm (that of 1030 ppm, from the only test with the compressor) exceeded the Table 4-1 limit. All the rest of the peak values were well within both Table 4-1 limits and the recommended 10 ppm VOC limit. Following initial calibration, calibration checks before air testing each succeeding test day at 19–21 ºC confirmed close agreement with expected readings and no recalibration was needed. However, for unexplained reasons, monitor #322 was spanned on one test day and monitor #324 was spanned on each test day.

Series 3. March to April 2001.

1. Four diving teams conducted testing on ten days — five days each week, for two weeks.
2. Testing entailed initially checking monitor calibrations at the beginning of each week and recalibrating the monitors if that were necessary. One of two designated divers inside the controlled-temperature “Hyperbaric Chamber and Helmet and Dress” facility performed these procedures.
3. Monitors were then issued to the teams, and air testing without calibration checks was conducted until the last day of each week, when monitors were checked and recalibrated if necessary. This failure to check calibration on a daily basis constituted a deviation from the Field Test document, but NNSY and NEDU had agreed to do so ahead of time to simplify testing during this last test series.
4. The first week, monitor #322 with air sampling kit #22 was issued to BRAVO team and tested on BRAVO Trailer — with scuba bottles, their LWDS, and ambient air.

5. The first week, monitor #324 with air sampling kit #12 was issued to CHARLIE team — which, like BRAVO team, has a trailer without environmental control systems. CHARLIE team also had a LWDS inside the trailer, and its divers completed testing with scuba bottles, their LWDS, and ambient air.
6. The second week, monitor #322 with air sampling kit #22 was issued to DELTA team and tested on DELTA Boat, a 30-foot, controlled-temperature facility with a FADS III system inside it. Testing was done on the DELTA FADS III and ambient air.
7. The second week, monitor #324 with air sampling kit #12 was issued to ECHO team — which, like DELTA team, had a controlled-temperature boat with a FADS III inside it. Testing was done on the ECHO FADS III and ambient air.

For the entire Series 3, calibration was done at ambient temperatures of 19–21 ºC; all testing was done at ambient temperatures of 9–26 ºC measured at the start of air monitoring. Peak gas values for the entire two-week period for both monitors ranged as follows: 18.8–22.3% O_2, 430–1180 ppm CO_2, 0–28 ppm CO, and 0.0–4.9 ppm VOCs.

The following breakdown of data summarizes some information on outlying gas values.

Monitor #322, week #1 testing of scuba bottles, the BRAVO LWDS, and ambient air on the BRAVO Trailer. For each of the five days, peak values measured at starting temperatures of 9–20 ºC ranged as follows: 21.0–21.3% O_2, 430–820 ppm CO_2, 0 ppm CO, and 0.0–0.3 ppm VOCs. <u>These peak values are within both Table 4-1 limits and the recommended 10 ppm VOC limit</u>.

Monitor #322, week #2 testing of the DELTA FADS III and ambient air on the DELTA boat. For each of the five days, peak values measured at 21–24 ºC ranged as follows: 21.3–21.6% O_2, 460–950 ppm CO_2, 0–22 ppm CO, and 0.1–2.3 ppm VOCs. For the three days when FADS III was tested, peak values ranged from 920 to 950 ppm CO_2 and 7–12 ppm CO. On one day a peak value of 22 ppm CO was measured from ambient air; on that day and the other day of ambient air testing, all the rest of the peak values for ambient air were well within Table 4-1 limits and the recommended 10 ppm VOC limit. <u>Overall, these data show some elevated CO_2 and CO readings that are close to — and, in one case for CO, above — Table 4-1 limits for these two gases</u>.

Monitor #324, week #1 testing of using scuba bottles, the CHARLIE LWDS, and ambient air on the CHARLIE Trailer. For each of the five days, peak values measured at 15–18 ºC ranged as follows: 18.8–21.6% O_2, 430–1180 ppm CO_2, 0–14 ppm CO, and 0.0–4.9 ppm VOCs. We are unsure why the one O_2 peak (minimum) reading was <20.0% from one of the two days of testing with the LWDS. <u>A second test day with an ambient air peak value of 1180 ppm CO_2 (exceeding the Table 4-1 limit for CO_2), a third test day with a scuba peak value of 14 ppm CO, and a fourth test day with a LWDS peak value of 4.9 ppm VOCs also resulted</u>. All the rest of the peak values from the testing were well within Table 4-1 limits and the recommended 10 ppm VOC limit.

Monitor #324, week #2 testing of the ECHO FADS III and ambient air on the ECHO boat. For each of the five days, peak values measured at 16–26 ºC ranged as follows: 21.1–22.3% O_2, 440–840 ppm CO_2, 0–28 ppm CO, and 0.0–1.6 ppm VOCs. The only readings of interest are an ambient air peak value of 28 ppm CO that exceeds the Table 4-1 limit for CO and two FADS III peak O_2 values (22.2% and 22.3%) that are slightly greater than Table 4-1 specifications. All the other testing peak values were well within Table 4-1 limits and the recommended 10 ppm VOC limit.

Calibration data for Series 3 are given in Tables 2A–2D, one table for each of the two test weeks, for each of the two monitors. In addition to the concentrations of the calibration gases, each table provides the following data:

1. "Prezero" values: gas readings when N_2 is sampled before any zeroing of the four sensors.

2. "Postzero" values: gas readings when N_2 is sampled after zeroing (if zeroing is required or done).

3. "Prespan" values: gas readings when span gas is sampled before any spanning of the four sensors.

4. "Postspan" values: gas readings when span gas is sampled after spanning (if spanning is required or done).

For each of the two test weeks, these calibration data were obtained on both the first test day (Monday, Day 1), when calibration was checked before air testing was begun, and the last test day (Friday, Day 5), when calibration was again checked after air testing had been completed for the week. Other than on the first day of the first week, when both monitors were fully calibrated (zeroed and spanned) before air testing, rezeroing and respanning were done only if they were required by the calibration rules described in the **FIELD TESTING** section and reiterated here.

Calibration rules for field testing: The monitor was *not* zeroed if N_2 readings were all less than 0.5% O_2, 100 ppm CO_2, 5 ppm CO, and 1.0 ppm VOC. Also, the monitor was *not* spanned if span gas readings were all within 0.5% O_2, 100 ppm CO_2, 5 ppm CO, and 1.0 ppm VOC of the span gas values. These ranges in gas readings allowable before zeroing or spanning was required facilitated examination of how much "drift" in calibration settings occurred with time.

When the monitor was not zeroed or spanned, Tables 2A–2D respectively list the notations "NZ" or "NS." All prezero or prespan readings for which the calibration rules required zeroing or spanning are typeset in boldface in the Tables. If the mandatory full calibration for monitor #322 is ignored on Day 1 of the first week, in one case (Day 5 of that week) an outlying O_2 reading of the span gas required respanning, and in another case (Day 5 of Week #2) an outlying CO_2 reading of the N_2 calibration gas required

rezeroing — although the monitor apparently was not rezeroed then. For monitor #324 on Day 5 of Week #1, both an outlying O_2 reading of the N_2 gas required rezeroing and an outlying VOC reading of the span gas required respanning. On Day 1 of Week #2, an outlying O_2 reading also required monitor #324 to be respanned.

NEDU Testing

Although some NEDU testing was done when four divers informally stepped through the procedures during a learning phase from January to February 2011, these divers completed a total of seven test days through a three-week period in March 2011. All calibration and testing were done indoors, at a controlled temperature in NEDU's Fleet Support facility. The divers used monitor #315 with air sampling kit #11 to test scuba bottles, an air bank manifold, and ambient air. As with the NNSY testing, we are reporting test results only from the completed data sheets provided to us. Along with the NNSY results, Table 1 summarizes the NEDU peak gas readings during air testing; NEDU data are also discussed in greater detail in the following paragraph.

Although monitor #315 did not require zeroing or spanning on the first test day, we are unsure about when it had last been calibrated. Following its calibration check at 24 ºC on that first test day, air was sampled from the variety of sources at ambient temperatures of 23–26 ºC. Peak values for each of the seven test days ranged as follows: 20.6–21.1% O_2, 360–490 ppm CO_2, 0–2 ppm CO, 0.0–0.1 ppm VOCs. These peak values are well within Table 4-1 limits and the recommended 10 ppm VOC limit. Calibration checks at 24–27 ºC on each of the three succeeding days following the first test day confirmed that the expected readings agreed closely with calibrations, and no recalibration was needed. However, testing was then stopped; when it resumed two weeks after the initial start date, a full calibration (as required by our rules) was made at 23 ºC. On the last two test days, calibration checks over a six-day period at 22–26 ºC again confirmed that expected readings closely agreed with calibrations, and no recalibration was needed.

Post testing check and calibration gas usage

After testing at both NNSY and NEDU was completed, the three air sampling kits were returned to our laboratory. In addition to checking the kits to ensure that all testing hardware was present and the monitors appeared to operate properly, we measured the pressure levels in the three pairs of calibration gas (N_2 and span gas) cylinders that had been originally installed in the kits. All initial pressures of the six cylinders before testing had been confirmed to be ~2000 psig. After these cylinders had been returned to NEDU, all of them were still in place on the sampling apparatus and had sufficient pressure (>400 psig) for further use. From the calibration information on the completed data sheets and from our confirmation that the posttesting pressures of all the spare cylinders that we had provided were ~2000 psig, none of the spare cylinders had apparently been used.

Calibration gas issues

After the field test had been completed, the relatively high O_2 readings observed during air testing at NNSY (Table 1) raised questions about the accuracy of the certified gas standards used for calibration. Therefore, in our NEDU laboratory we followed procedures previously described[10] to analyze the O_2 in the three span gas cylinders used at NNSY and NEDU. We emphasize that reconciling analytical results from different laboratories can often be difficult and that, as a research laboratory, our NEDU facility is not certified in commercially analyzing samples for others. But with that said, our results suggested that the O_2 concentrations of one or more of the three span gas cylinders might be up to 0.4% absolute lower than the certified values — which ranged from 21.2–21.5% O_2 but were within the analytical uncertainty of ±2% relative (or ±0.4% absolute) O_2 defined by the gas supplier.

In addition to any monitor error that might be present, since span gas concentrations are entered into the monitors before they are calibrated, the level of uncertainty associated with these concentrations results in similar uncertainties in the gas readings when diving air is being sampled. Thus, if the true O_2 concentration of any of the span gas cylinders were lower than that listed on the cylinder certificate, this disparity may at least partly explain the higher-than-expected O_2 readings seen in some of the NNSY testing. We emphasize that the uncertainties about the certified standard concentrations used in our testing (±2% relative for O_2 and CO_2; ±5% for CO and isobutylene) are greater than the uncertainties for primary standards of similar mixtures: e.g., primary standards obtained recently from the same supplier were stated as being ±1% relative for all four components O_2, CO_2, CO, and isobutylene.

Problems during both field tests

Both NNSY and NEDU seemed to have some initial problems in correctly following the air monitor calibration procedures. Early results and conversations (by both E-mail and phone) suggested that the N_2 and span gas procedures might have been reversed at times: i.e., the span gas had been used to zero the monitor, and then the N_2 had been used to span the monitor. We are unsure about how this problem arose, although we suspect that, as the test personnel suggested (see item 4 in the **Tester comments and suggestions** section below), better labeling of the calibration gases might have helped avoid the error. However, after test personnel had acquired a little experience with testing, both the NEDU and NNSY calibration data suggest that calibration was generally done correctly.

Batteries

Due to the relatively short times (generally several hours per day) that testing was done each day, we had little opportunity to evaluate the duration of the nickel metal hydride batteries in the air monitors used in the field. However, no battery problems were

reported when the monitors that were supposed to have been recharged before each test day were used.

Tester comments and suggestions

Test personnel at both NNSY and NEDU were enthusiastic about the air sampling kit and monitor, and they offered the following comments and suggestions, some of which are closely paraphrased if not reported in the testers' own words.

1. Use quick-disconnects (QDs) on all locations where connections are made and broken, including the Teflon line connecting the monitor to the reducer. The QDs will make the procedures faster, simpler, and more user friendly than the current ¼-inch A/N fittings that require (1) using wrenches to install and remove them and (2) recommended leak testing each time after a new attachment is made. Fleet diving operations are often conducted under severe time constraints, and air sampling procedures should be designed to require the least amount of time possible and still ensure acceptable diving air.

2. The operating procedures in the Field Test document were found to be appropriate for initial training and use. However, after a little experience using the air sampling kit, testers thought that a shorter data sheet and a shorter and perhaps more visual (e.g., with pictures of some of the hardware) set of operating procedures ("OPs") adapted from the long version would more practical for general Fleet use. One tester thought that such an OP could be limited to two to three laminated two-sided pages.

3. The N_2 calibration bottle has a right-hand threaded CGA 580 valve, while the span gas bottle has a left-hand threaded CGA 590 valve, with these specifications driven by regulations pertaining to the specific gas mixtures within each bottle (the regulations consider span gas to be equivalent to air). Each bottle should be labeled to show the direction of the threads, to prevent possible crossthreading of the brass valves when a new tester first uses the air sampling kit or when the tester is in a rush.

4. Labeling of the various fittings and hardware in the sampling kit (including labeling the calibration gases "N_2" and "span") would help new or inexperienced testers to avoid having to rummage through the entire kit and enable them, instead, to quickly and accurately identify the proper hardware needed for testing a specific air source.

5. Both NNSY and NEDU personnel indicated that all the hardware needed for their testing was contained in the kits.

Conclusions

1. Field testing went well overall, with constructive comments from the testers about the monitor and procedures, and revealed no big surprises about the reliability and performance of the monitor and testing hardware.

2. In general, air quality as measured during field testing was good; most of the peak values were within Table 4-1 limits and the recommended 10 ppm VOC limit. However, the NNSY data showed some elevated CO_2 and CO readings that were close to, and in a few cases above, Table 4-1 limits for these two gases.

3. Some elevated O_2 readings during the NNSY testing may at least partly result from the analytical uncertainty associated with the *certified calibration standards* — an uncertainty thought to be within the specifications of the gas standards. If a more accurate analysis is needed, we expect that small additional costs for *primary standards* with less analytical uncertainty (costs we have confirmed with the supplier of the calibration cylinders used with the NEDU kit: see Appendix C) might be justified.

4. One set of calibration gas cylinders provided sufficient gas for each of the three air sampling kits during field testing at NNSY and NEDU. This finding suggests that downsizing the original calibration cylinders in the NAVSEA 00C kit should not create significant problems with testing in the field — especially if and when the air monitor's calibration frequency becomes somewhat relaxed.

5. The limited calibration data from Series 3 at NNSY suggest that, under field conditions where ambient temperatures are often not controlled and monitors are moved about and used on diving trailers and boats, weekly shifts in calibration that are outside the field testing "rules" that we have defined and that are outside what we judge to be acceptable can result.

6. For the testing done indoors at both NNSY and NEDU (with little reported transport of the calibrated air monitor and sampling kit), calibration stability appears to be better than that seen in NNSY Series 3.

LABORATORY TESTING OF THE DEWPOINT METER

Initial testing using the reducer and HP sampling whip from air sampling kit #21 to deliver gas to the two dewpoint probes, each within its own sampling cell, showed that dewpoint readings failed to equilibrate — even after three hours of gas flow. By the end of the two- to three-hour testing periods, the dewpoint readings from a commercially obtained cylinder of "ultra zero" air (with a water specification of <2 ppm [an equivalent dewpoint of ≤72 ºC]) continued to decrease slowly and ranged down to –55 ºC. Similar testing of a 36 ppm water in air certified standard (an equivalent dewpoint of ≤51 ºC) showed dewpoint readings decreasing to –44 ºC after 90 min and still diminishing. Even after we verified that the bleeder valve on the upstream side of the reducer was sufficiently opened to allow an audible purge of the HP whip and that the recommended one-half turn of the leakage adjustment screw on the sampling cell was increased to up to four turns open, both of these steps designed to improve delivery of the dry air standard to the dewpoint probe failed to improve equilibration time.

Although we had been aware that for gas with low dewpoints (≤ –60 ºC), the Vaisala probe might require far more than one hour to equilibrate, we contacted Vaisala to discuss our unexpected observations that even after two to three hours, the dewpoint readings of dry air were still decreasing and were far from expected values. On the basis of our information that our testing reducer had an unencumbered delivery flow rate of ~110 to 115 mL/min, we informed Vaisala that the flow rate of test gas to the dewpoint probe would be equivalent to this flow or less, depending on the resistance introduced by the sampling cell and leakage vent. Vaisala representatives responded that they believed this flow would be too low and would result in equilibration times slower than normal with the dewpoint probe.

Our next steps were to evaluate the actual flow through the sampling cell, and the effect of the leakage adjustment screw, by connecting our previously verified rotameter in series between the reducer and the sampling cell. We found that with the leakage screw given the recommended one-half turn open, we observed no flow with the rotameter, presumably because the low pressure downstream of the reducer was insufficient to push gas through the small leakage orifice. For the full reducer flow to occur, the leakage screw needed to be turned one and one-half turns open. This observation suggested that our prior testing with the leakage screw open at least this much delivered full reducer flow — although this flow was accompanied by the equilibration problems described in the opening paragraph of this section. Consequently, with this information and the Vaisala recommendations in hand, we concluded that the delivery flow through the sampling cell had to be increased to get a faster response from the dewpoint meter.

Using the setup described in the **METHODS** section, we removed the reducer from the delivery circuit and compared deliveries of test gas rates of 150 mL/min and 500 mL/min to the dewpoint sampling cell. Tests with two different probes and sampling cells showed that, after 30 minutes with gas flows of ~150 mL/min, dewpoints measured from the ultra zero air gas ranged from –54 to –59 ºC (and continued to decline slowly), and with flows of ~500 mL/min, they ranged from –65 to –69 ºC (and again continued to decline slowly): The dewpoint response was faster with the higher flow rate.

To determine a practical approach toward water testing of diving gas, we conducted similar testing with 36 ppm water in air standard and an equivalent dewpoint of ~ –51 ºC, which is close to the total water requirement of 0.02 mg/L (dewpoint of –53 ºC) for diving air from commercial sources (Table 4-2).[1] After ~7 min (usually the earliest time that dewpoint measurements could be taken after the automatic sensor purging and autocalibration had been turned on for measuring low dewpoints[7]), dewpoints of –48 to –49 ºC were observed, readings apparently stabilized by 30 min at –50 ºC. On the basis of these findings, dewpoints taken from air samples in this manner and with a delivery flow of ~500 mL/min may be one approach for conducting field testing. However, our limited testing suggests that, even when this technique is restricted to dewpoints equal to the current water standard in Table 4-2, measurements taken after ~7 min may still be stabilizing and thus are slightly higher than the actual dewpoints. Furthermore,

adoption of this (or a similar) method would necessitate that — following a presumed hardware change to the reducer — delivery flow from the reducer be increased to ~500 mL/min. Or, if the goals are to minimize reducer flow to conserve calibration gas during monitor calibration and to ensure quickly equilibrating dewpoints, the necessary delivery flow might perhaps be somewhere between 150 and 500 mL/min.

Conclusions

1. Measuring low gas dewpoints with the Vaisala dewpoint meter requires long stabilization periods, a problem we believe that many, if not all other, commercially available dewpoint monitors share. The low gas flows delivered by the reducers originally supplied in the NAVSEA 00C air sampling kit and now used in the new NEDU air sampling kit further prolong these stabilization periods.

2. A practical procedure has been demonstrated for measuring dewpoints with the NEDU sampling kit in air down to ~ –50 ºC, but this procedure would require that the gas flow delivered by the kit's reducer be increased (presumably by a hardware adjustment to the current reducer) to ~500 mL/min — or perhaps to a flow level somewhat less, to conserve gas. At our request, Geotechnical Instruments has completed some testing suggesting that a flow of 500 mL/min is acceptable for normal operation of the Diveair2. However, after any modification in reducer function is made, limited laboratory testing should be completed to verify that both the Diveair2 and the Vaisala dewpoint meter perform acceptably.

3. We rely on NAVSEA 00C to direct us how to proceed regarding any modification of the reducer in the NEDU air sampling kit or any further testing of the dewpoint meter.

FINAL CONCLUSIONS AND RECOMMENDATIONS

1. The record of failures with the first production Diveair2 monitors suggests that, until proven otherwise, these monitors should be used with caution — and that, when it is convenient, an experienced Navy user should confirm all Navy-owned monitors to be in acceptable working condition. This confirmation should verify (1) acceptable gas readings of the two calibration gases (i.e., zero N_2 and span gas) following calibration and (2) normal operation of the monitor's commonly used functions.

2. The new NEDU air sampling kit (version 1.0 ASK) that we have developed and described in this report eliminates many problems with, and improves the performance of, the existing NAVSEA 00C kit. We recommend that NAVSEA 00C adopt this new NEDU air sampling kit as the only one approved for use with the Diveair2 air quality monitor. Existing NAVSEA 00C air sampling kits can be converted, as needed, into the NEDU air sampling kits. In addition, NAVSEA 00C should approve only one air sampling data log sheet, via listing it on the NAVSEA 00C Web site or including it in the procedures approved for the NEDU air sampling kit.

3. Final procedures for using the NEDU air sampling kit (with these procedures designated as version 1.0 OP-ASK) are provided in **Appendix A** and incorporate both results from our testing and user input. Photos of our kit are included in **Appendix B,** details of the new hardware items in the NEDU kit are in **Appendix C**, and shipping procedures for that kit are in **Appendix D**.

4. The **Appendix A** procedures have sufficient detail to provide both initial training of personnel and a general reference for using the air sampling kit. However, from comments during our field testing we expect that, after a little experience with the NEDU kit, many users may prefer a shorter, perhaps more visual procedural document or OP based on **Appendix A.** Such an OP may be more practical than **Appendix A** for general Fleet use.

5. We believe that Navy Fleet users are in the best position to develop any shortened OP for the NEDU air sampling kit, but we recommend that NEDU review any Fleet-developed OP before NAVSEA 00C confers its official approval on such a document. To eliminate the chances for users to be confused about what procedures comprise the officially approved version, we also recommend having only one detailed set of approved procedures (as in **Appendix A** or an equivalent) and one approved shortened OP version of these procedures.

6. We recommend that, for those air sampling kits and Diveair2 monitors that NAVSEA 00C distributes to Fleet users upon their request, NAVSEA 00C maintain a system that ensures that these kits and monitors are (1) in acceptable operating condition when shipped out, and (2) rechecked when returned, so that any problems found are corrected. We are unaware that such a quality control system now exists. However, in our opinion the best approach would be for users to own, maintain, and be responsible for the air sampling kits and monitors that they use.

7. On the basis of our discussion about the original NAVSEA 00C air sampling kit in this report, we recommend that NAVSEA implement the following two actions:

a. Ensure that the Diveair2 certificates of calibration provided by Geotechnical Instruments are held by ESSM, rather than included in the sampling kit, so that these certificates will not be lost.

b. Remove the two videos about use of the Diveair2 from the NAVSEA 00C Web site, since they are of little value for either the original air sampling kit or the new NEDU air sampling kit.

8. Field testing of the new NEDU air sampling kit went well, revealing no big surprises about the reliability and performance of the air monitor and testing hardware, and it suggests that downsizing of the original calibration cylinders in the NAVSEA 00C kit should not create significant problems in field testing.

9. In general, air quality measured during field testing was good: Most of the peak values were within Table 4-1 limits and the recommended 10 ppm VOC limit. However, some results showed elevated CO_2 and CO readings that were close to, and in a few cases, greater than the Table 4-1 limits for these two gases.

10. We recommend that NAVSEA 00C and NEDU discuss whether more precise calibration standards are needed for the air sampling kit and, if such a more accurate analysis of diving air is needed, whether the small additional cost of — and less analytical uncertainty expected for — such standards would be justified.

11. For indoor air testing where the test gear remains inside at one test site and the ambient temperature is controlled, calibration frequency for the monitor can probably be reduced — from the current daily calibration recommended by NEDU[2] — to once a week. However, the daily calibration requirement should probably remain for other testing scenarios. These recommendations have been incorporated into the **Appendix A** final procedures for using the NEDU air sampling kit.

12. On the bases of comments and suggestions from personnel involved with the field testing, NAVSEA 00C may want to consider implementing some of the following changes to the NEDU air sampling kit, ideas discussed in detail in the **FIELD TESTING OF THE NEDU AIR SAMPLING KIT** section:

a. Using QDs on all NEDU air sampling kit locations where connections are made and broken, including the Teflon line connecting the monitor to the reducer.

b. Labeling the various fittings and hardware in the sampling kit (including labeling of the calibration gases "N_2" and "span").

13. We await NAVSEA 00C's direction about how to proceed regarding any modification of the reducer in the NEDU air sampling kit to facilitate dewpoint measurements or further testing of the dewpoint meter.

14. The new NEDU air sampling kit and its Diveair2 air quality monitor may be useful for improving other Navy procedures, including (1) screening of ballast tank atmospheres during underwater ship husbandry operations on submarines,[10] (2) Dry Deck Shelter screening of submarine air banks before that air is used for diving or other operations, and (3) other applications requiring that diving gases and atmospheres are chemically safe.

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Table 1. Field Testing Results: NNSY and NEDU

Test Series	Monitor# Week#	Peak Values: Range			
		O_2 (%)	CO_2 (ppm)	CO (ppm)	VOCs (ppm)
NNSY TESTING					
Series 1		21.0–21.8	330-600	0	0.0–0.6
Series 2		21.1-21.7	290-1030 **(1030)**	0	0.0–0.4
Series 3	**Entire Series 3**	18.8-22.3 **(18.8,22.2, 22.3)**	430-1180 **(1180)**	0-28 **(22,28)**	0.0-4.9
	#322 Week #1	21.0–21.3	430-820	0	0.0–0.3
	#322 Week #2	21.3-21.6	460-950	0-22 **(22)**	0.1-2.3
	#324 Week #1	18.8-21.6 **(18.8)**	430-1180 **(1180)**	0-14	0.0-4.9
	#324 Week #2	21.1-22.3 **(22.2,22.3)**	440-840	0-28 **(28)**	0.0-1.6
NEDU TESTING					
	#315	20.6-21.1	360-490	0-2	0.0-0.1

Table 1 individual peak values (**BOLDFACE** inside parentheses) meet neither the Table 4-1 specifications for O_2, CO_2, and CO nor the NEDU-recommended limit of 10 ppm for VOCs.

Table 2A. NNSY Calibration Results from Field Testing Series 3: #322, Week #1

Test Condition	Monitor Readings			
	O_2 (%)	CO_2 (ppm)	CO (ppm)	VOCs (ppm)
Actual N_2 Gas	**0.0**	**0**	**0**	**0.0**
Prezero Day 1 Day 5	0.1 0.0	M 30	0 0	0.0 0.0
Postzero Day 1 Day 5	0.0 NZ	0 NZ	0 NZ	0.0 NZ
Actual Span Gas	**21.2**	**1000**	**21**	**10.0**
Prespan Day 1 Day 5	20.7 **20.4**	**1120** 1040	20 19	10.1 10.4
Postspan Day 1 Day 5	21.2 21.0	1000 1000	20 20	10.0 9.9

Prezero and Prespan values in **BOLD** indicate values outside the acceptable range defined by the field testing calibration rules and thus requiring monitor zeroing or spanning. Day 5 **BOLD** values suggest a significant shift in calibration from Day 1 for those specific gases.

M = missing data. NZ denotes that the monitor was not zeroed.

Table 2B. NNSY Calibration Results from Field Testing Series 3: #322, Week #2

Test Condition	Monitor Readings			
	O_2 (%)	CO_2 (ppm)	CO (ppm)	VOCs (ppm)
Actual N_2 Gas	**0.0**	**0**	**0**	**0.0**
Prezero Day 1 Day 5	0.0 0.0	60 **100**	0 0	0.0 0.0
Postzero Day 1 Day 5	NZ NZ	NZ NZ	NZ NZ	NZ NZ
Actual Span Gas	**21.2**	**1000**	**21**	**10.0**
Prespan Day 1 Day 5	21.6 21.4	1000 1050	21 21	9.3 9.3
Postspan Day 1 Day 5	NS NS	NS NS	NS NS	NS NS

Prezero and Prespan values in **BOLD** indicate values outside the acceptable range defined by the field testing calibration rules and thus requiring monitor zeroing or spanning. Day 5 **BOLD** values suggest a significant shift in calibration from Day 1 for those specific gases.

NZ and NS denote that the monitor was not zeroed or not spanned.

Table 2C. NNSY Calibration Results from Field Testing Series 3: #324, Week #1

Test Condition	Monitor Readings			
	O_2 (%)	CO_2 (ppm)	CO (ppm)	VOCs (ppm)
Actual N_2 Gas	**0.0**	**0**	**0**	**0.0**
Prezero Day 1 Day 5	0.1 **-0.8**	M 10	0 0	0.0 0.0
Postzero Day 1 Day 5	-0.9 0.0	0 10	0 0	0.0 0.0
Actual Span Gas	**21.5**	**1000**	**21**	**10.0**
Prespan Day 1 Day 5	**19.8** 21.9	1100 1060	21 20	9.2 **11.2**
Postspan Day 1 Day 5	21.5 21.4	1000 990	20 20	9.9 9.9

Prezero and Prespan values in **BOLD** indicate values outside the acceptable range defined by the field testing calibration rules and thus requiring monitor zeroing or spanning. Day 5 **BOLD** values suggest a significant shift in calibration from Day 1 for those specific gases.

M = missing data.

Table 2D. NNSY Calibration Results from Field Testing Series 3: #324, Week #2

Test Condition	Monitor Readings			
	O_2 (%)	CO_2 (ppm)	CO (ppm)	VOCs (ppm)
Actual N_2 Gas	**0.0**	**0**	**0**	**0.0**
Prezero Day 1 Day 5	0.0 0.0	10 30	0 0	0.0 0.0
Postzero Day 1 Day 5	NZ NZ	NZ NZ	NZ NZ	NZ NZ
Actual Span Gas	**21.5**	**1000**	**21**	**10.0**
Prespan Day 1 Day 5	**22.3** 21.9	960 970	22 21	9.0 9.1
Postspan Day 1 Day 5	NS NS	NS NS	NS NS	NS NS

Prezero and Prespan values in **BOLD** indicate values outside the acceptable range defined by the field testing calibration rules and thus requiring monitor zeroing or spanning. <u>Day 5 **BOLD** values suggest a significant shift in calibration from Day 1 for those specific gases</u>.

NZ and NS denote that the monitor was not zeroed or not spanned.

FIGURE 1A.
O2 Accuracy: 25C
Means and SDs, N=5-15

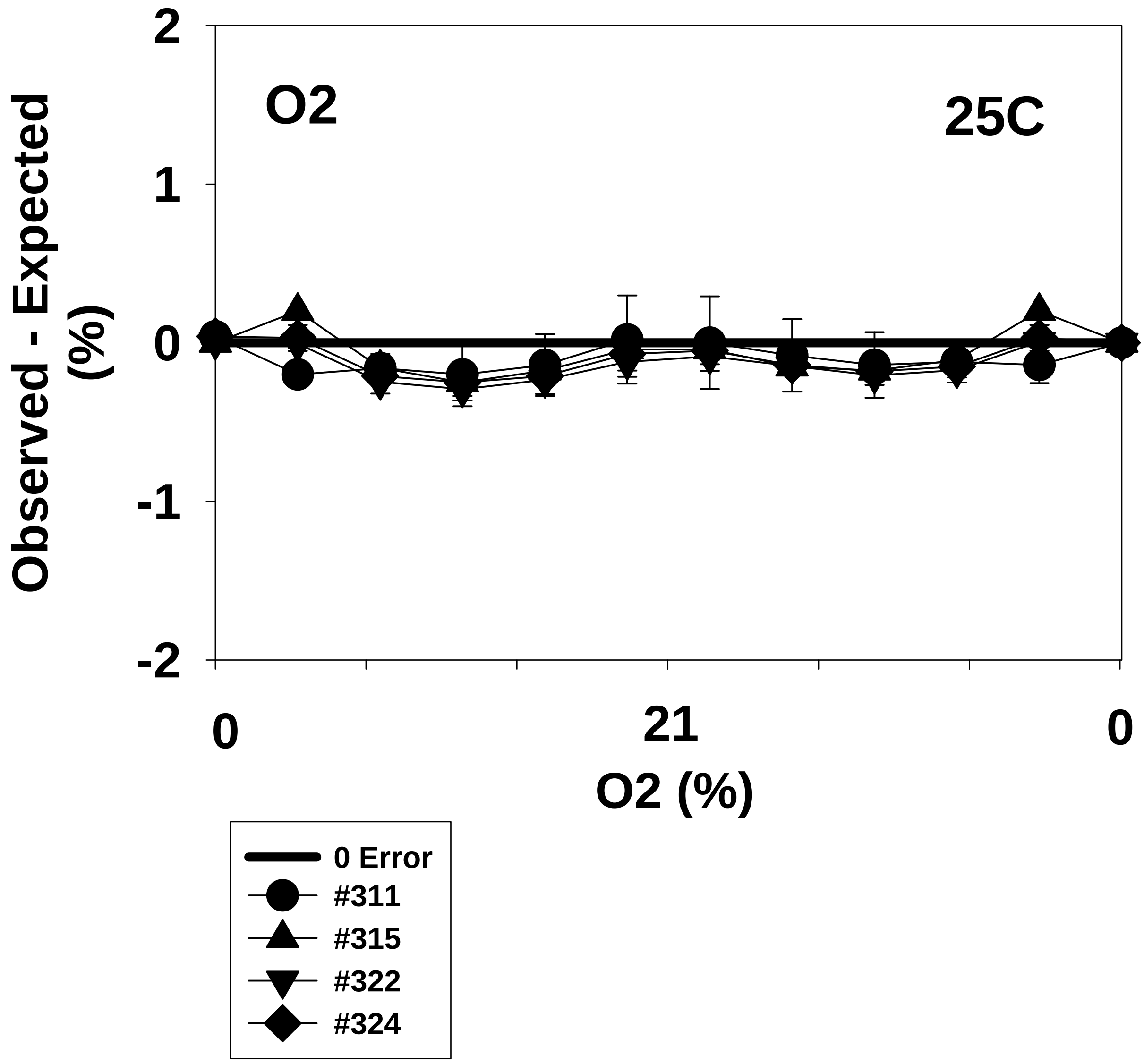


FIGURE 1B.
O2 Accuracy: 42C
Means and SDs, N=3

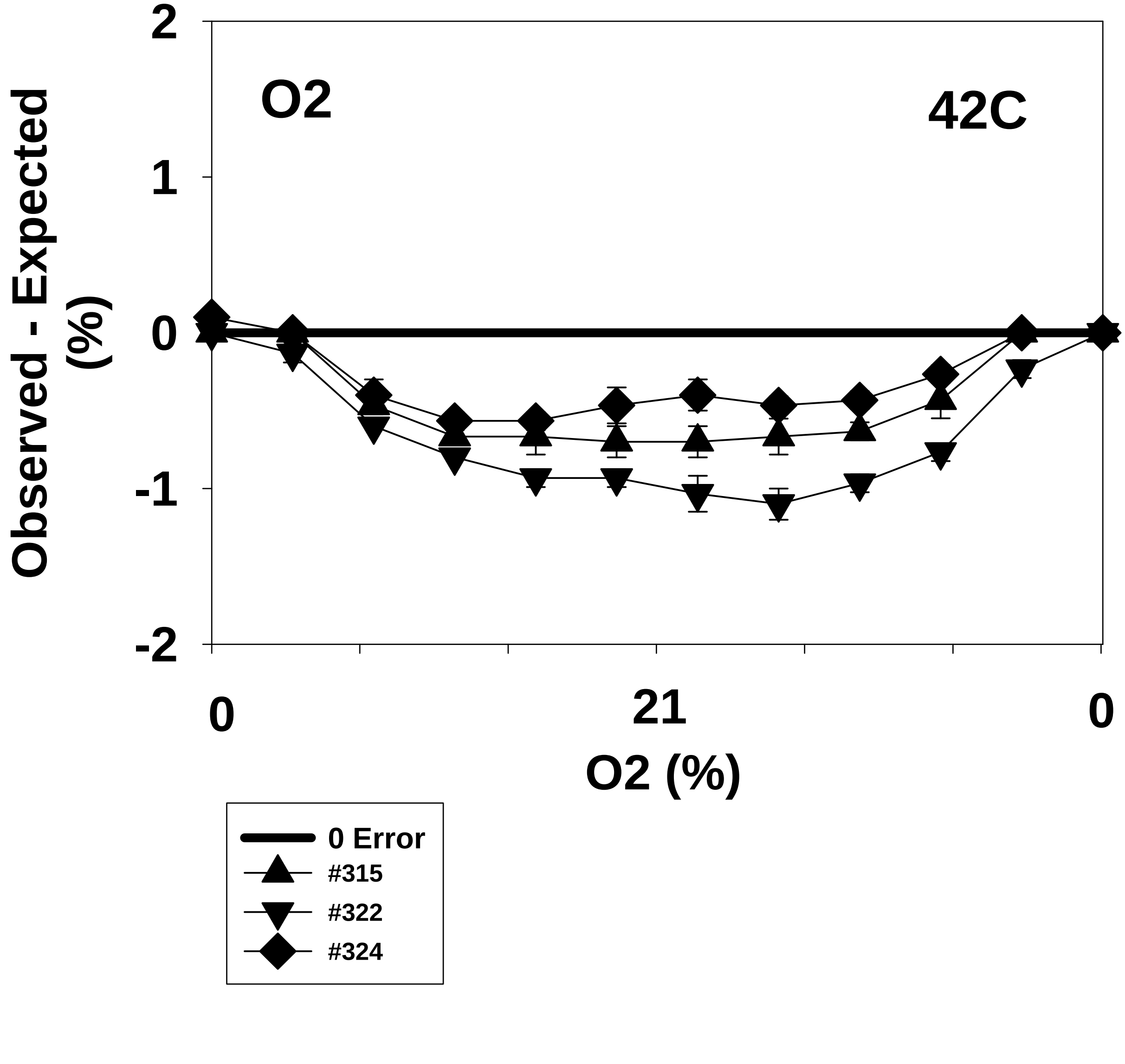


FIGURE 1C.
O2 Accuracy: 5C
Means and SDs, N=2-3

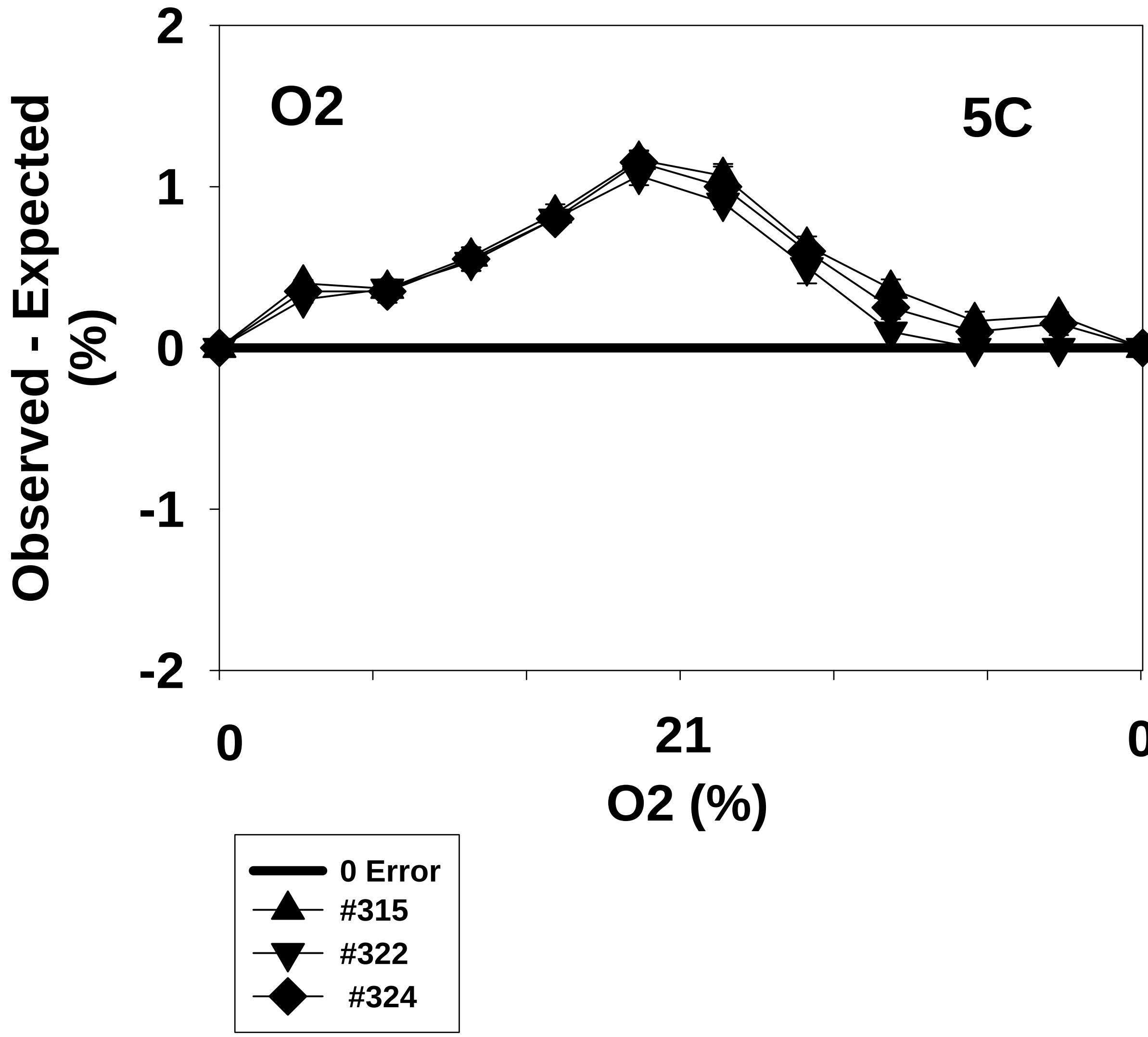


FIGURE 2A.
CO2 Accuracy: 25C
Means and SDs, N=5-15

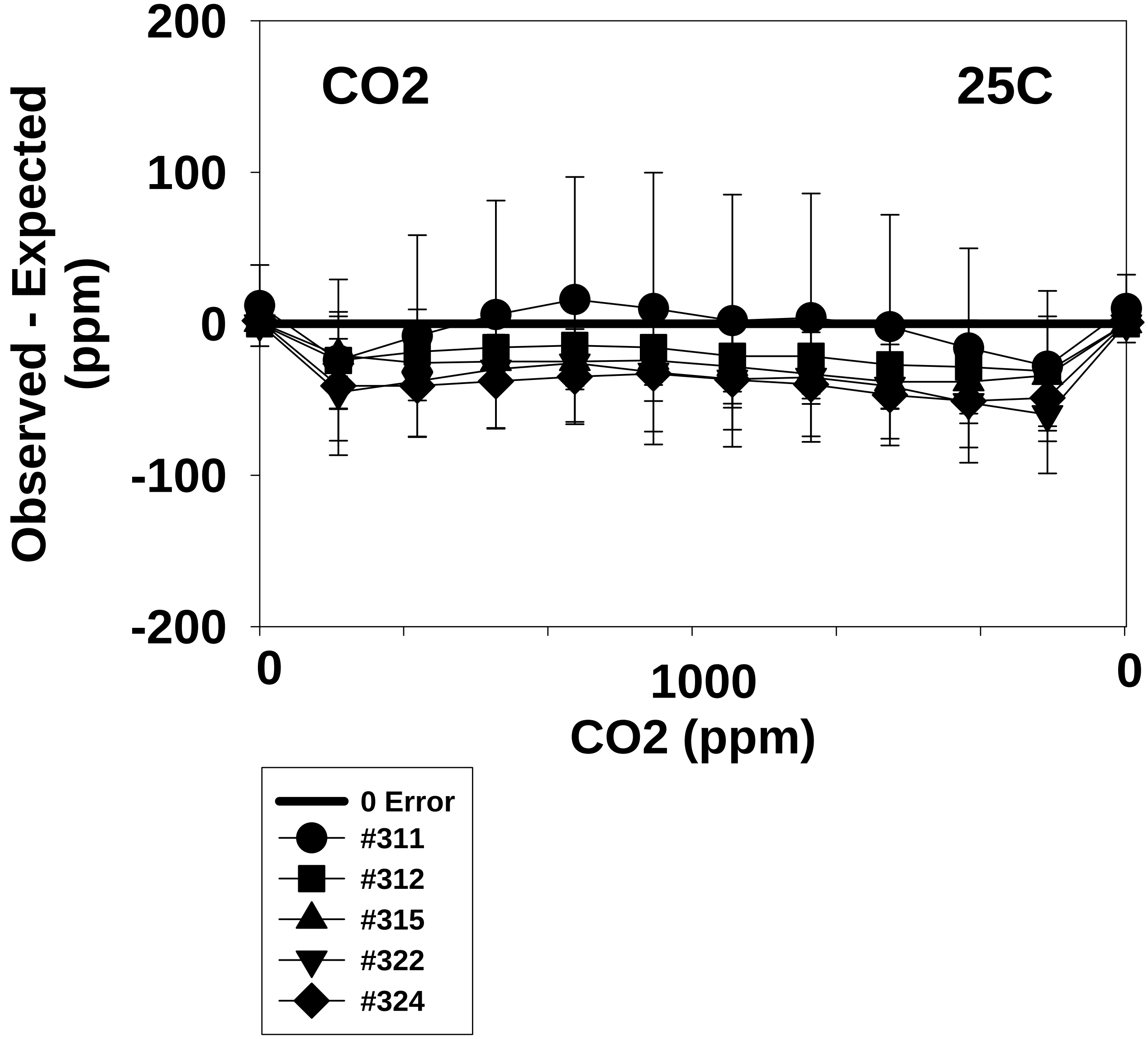


FIGURE 2B.
CO2 Accuracy: 42C
Means and SDs, N=3

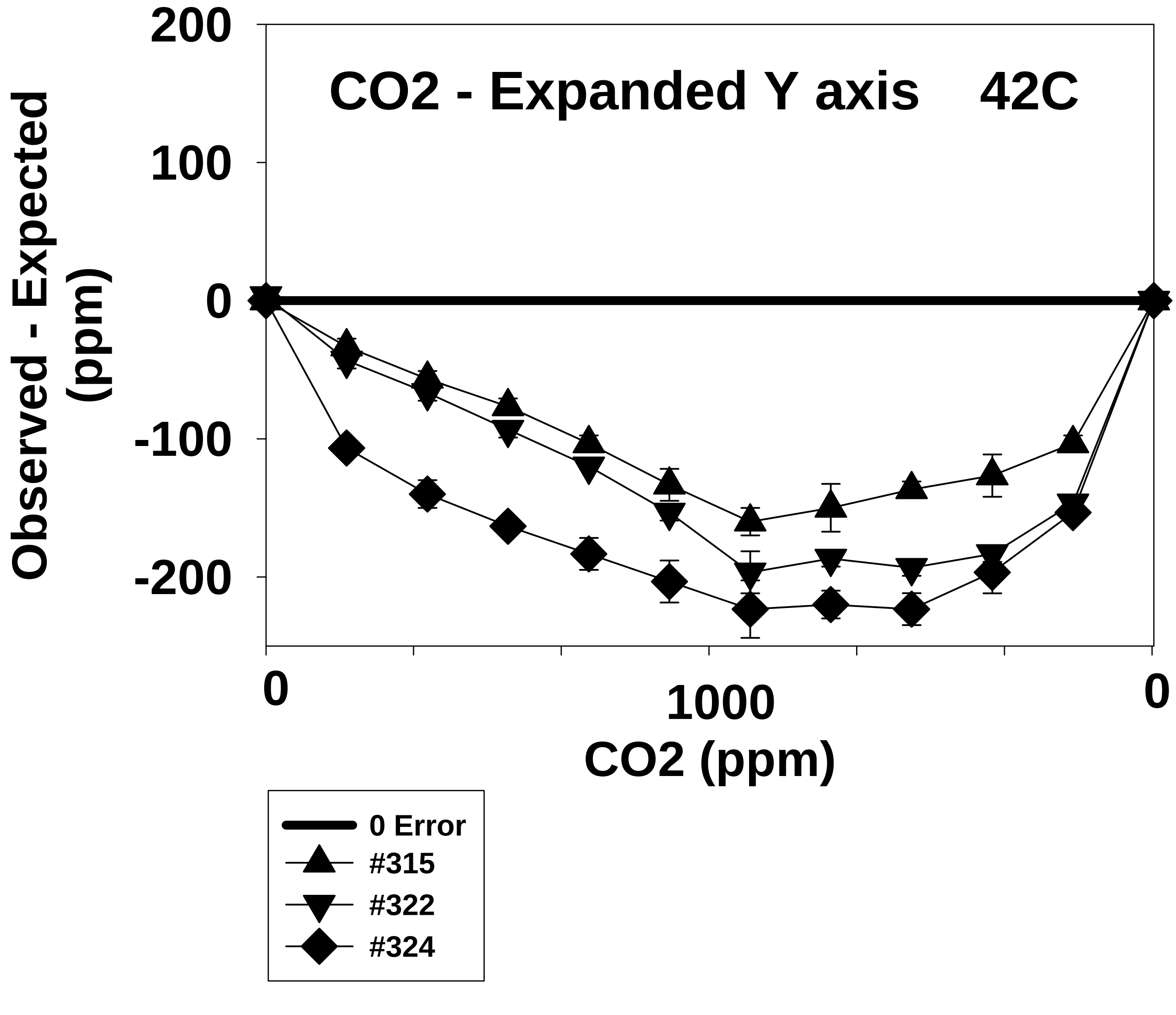


FIGURE 2C.
CO2 Accuracy: 5C
Means and SDs, N=2-3

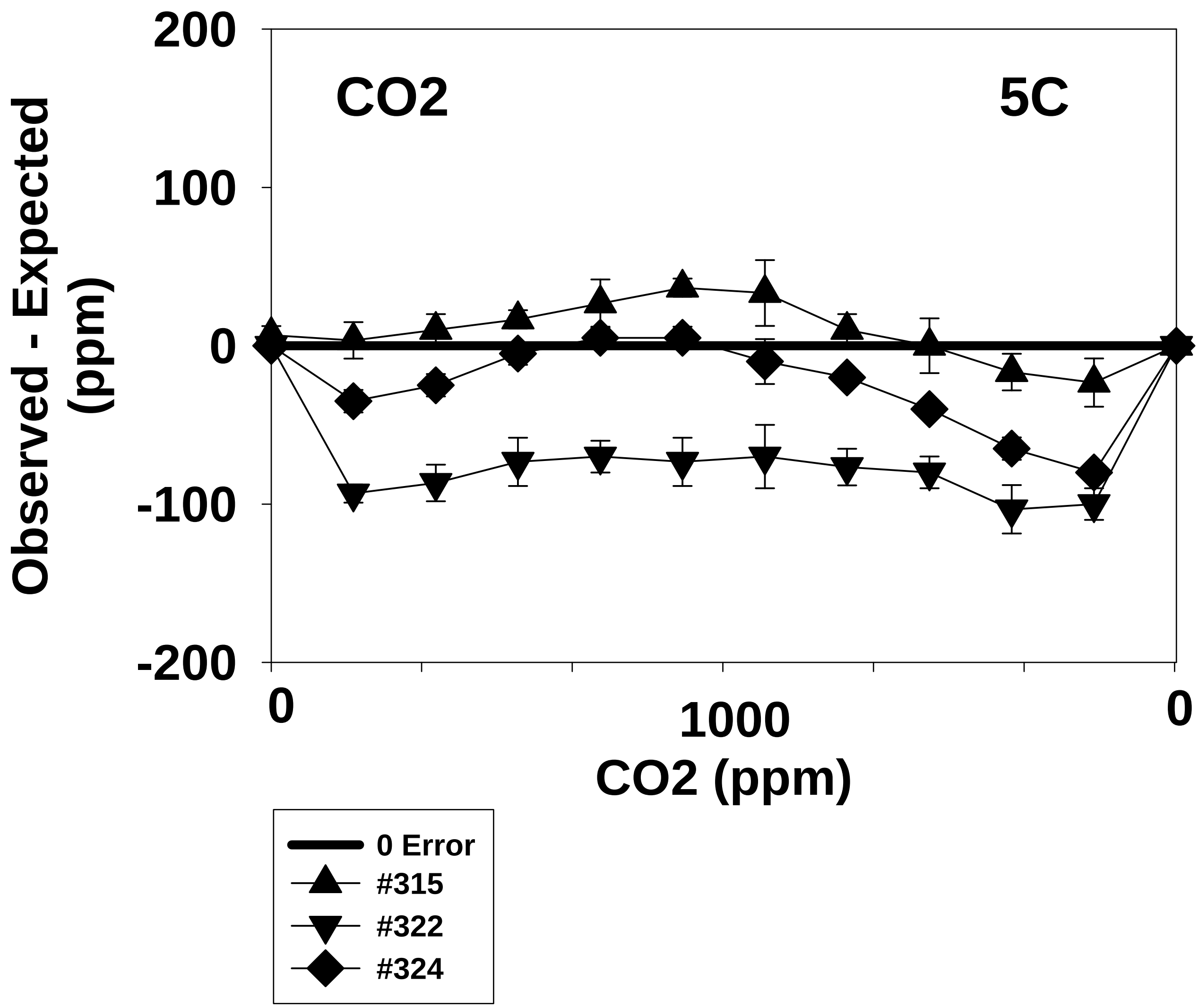


FIGURE 2D.
CO_2 Accuracy: 42C
Final Prototype
Means and SDs, N=4-8

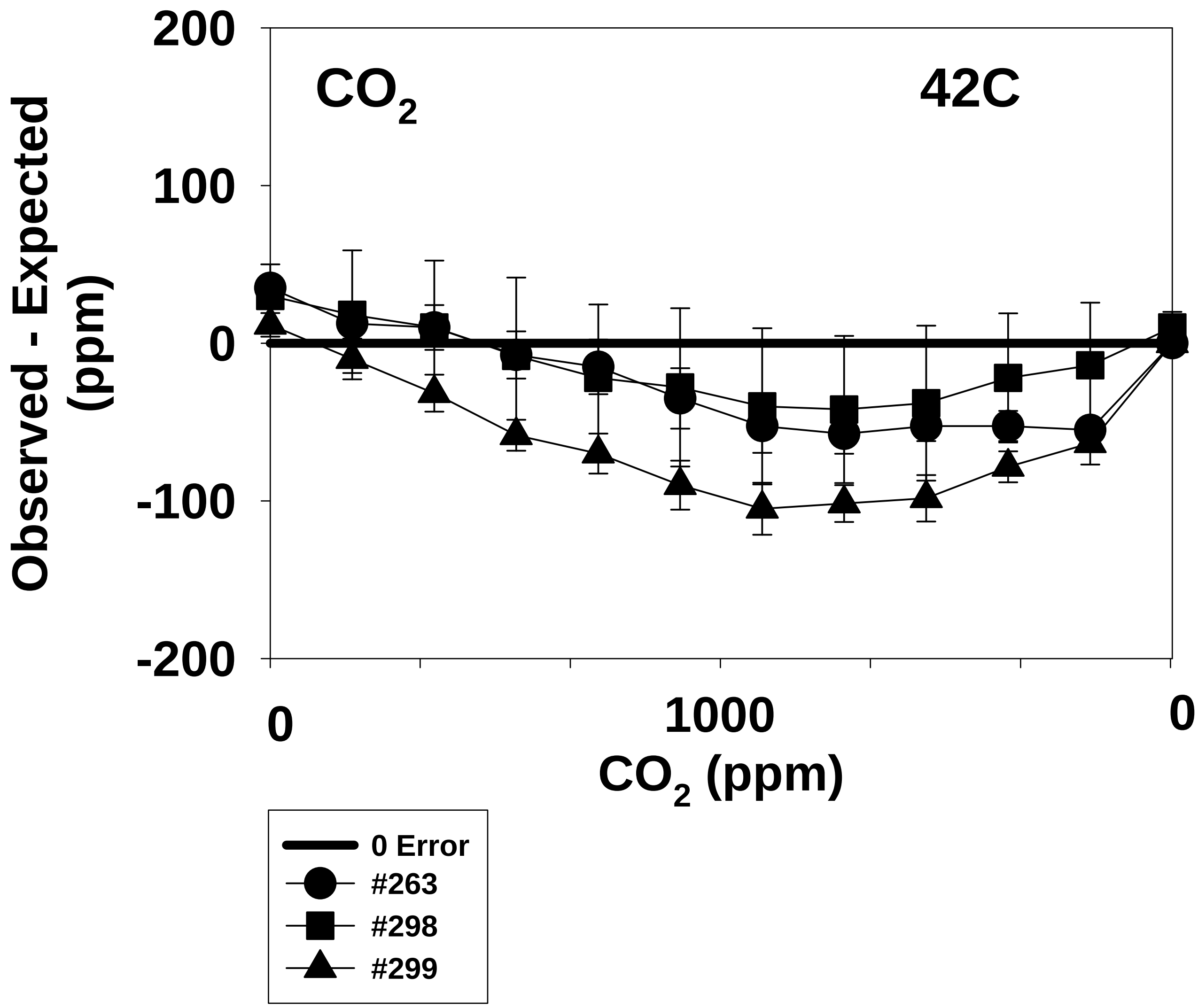


FIGURE 2E.
CO_2 Accuracy: 5C
<u>Final Prototype</u>
Means and SDs, N=4-7

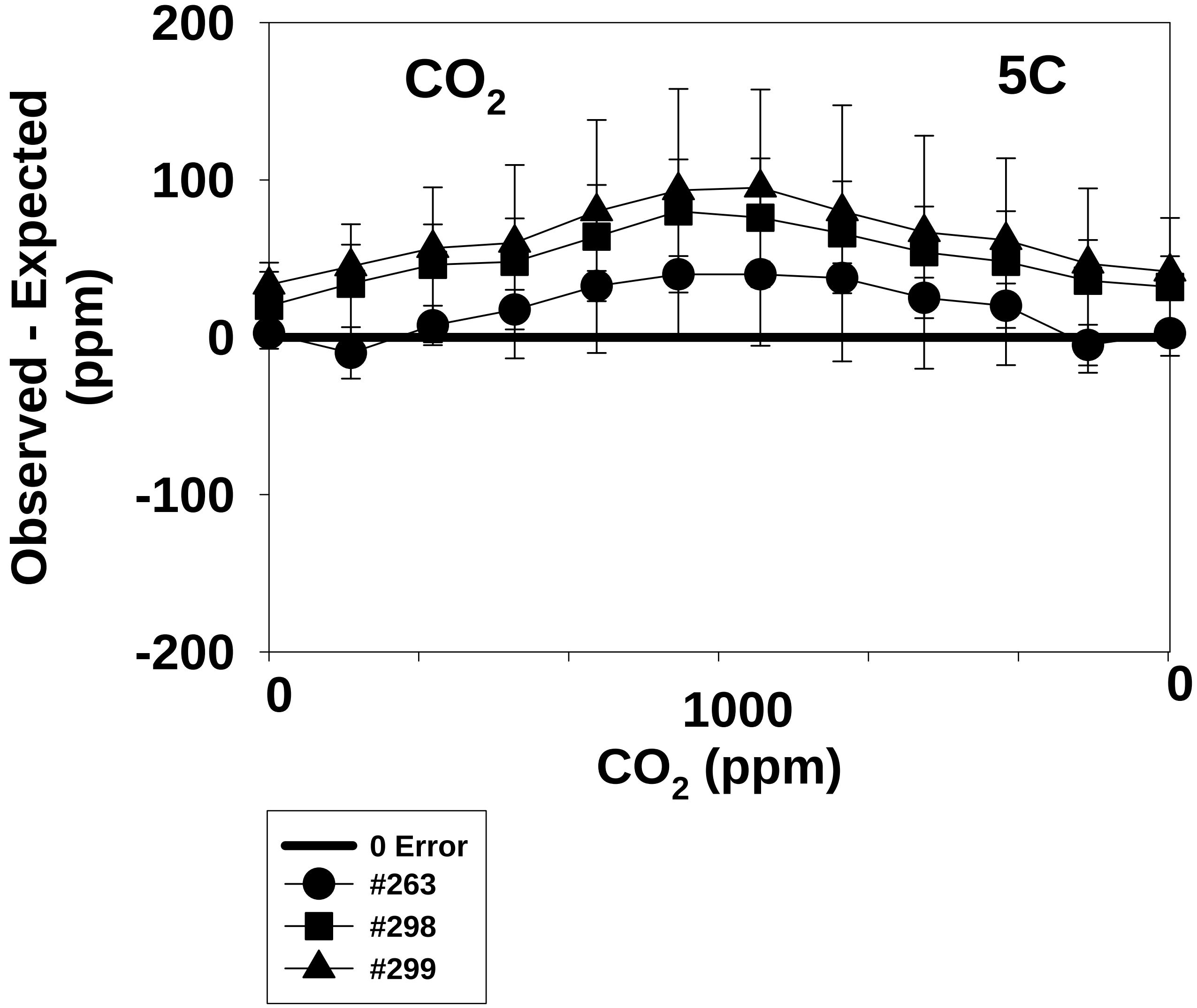


FIGURE 3A.
CO Accuracy: 25C
Means and SDs, N=7-15

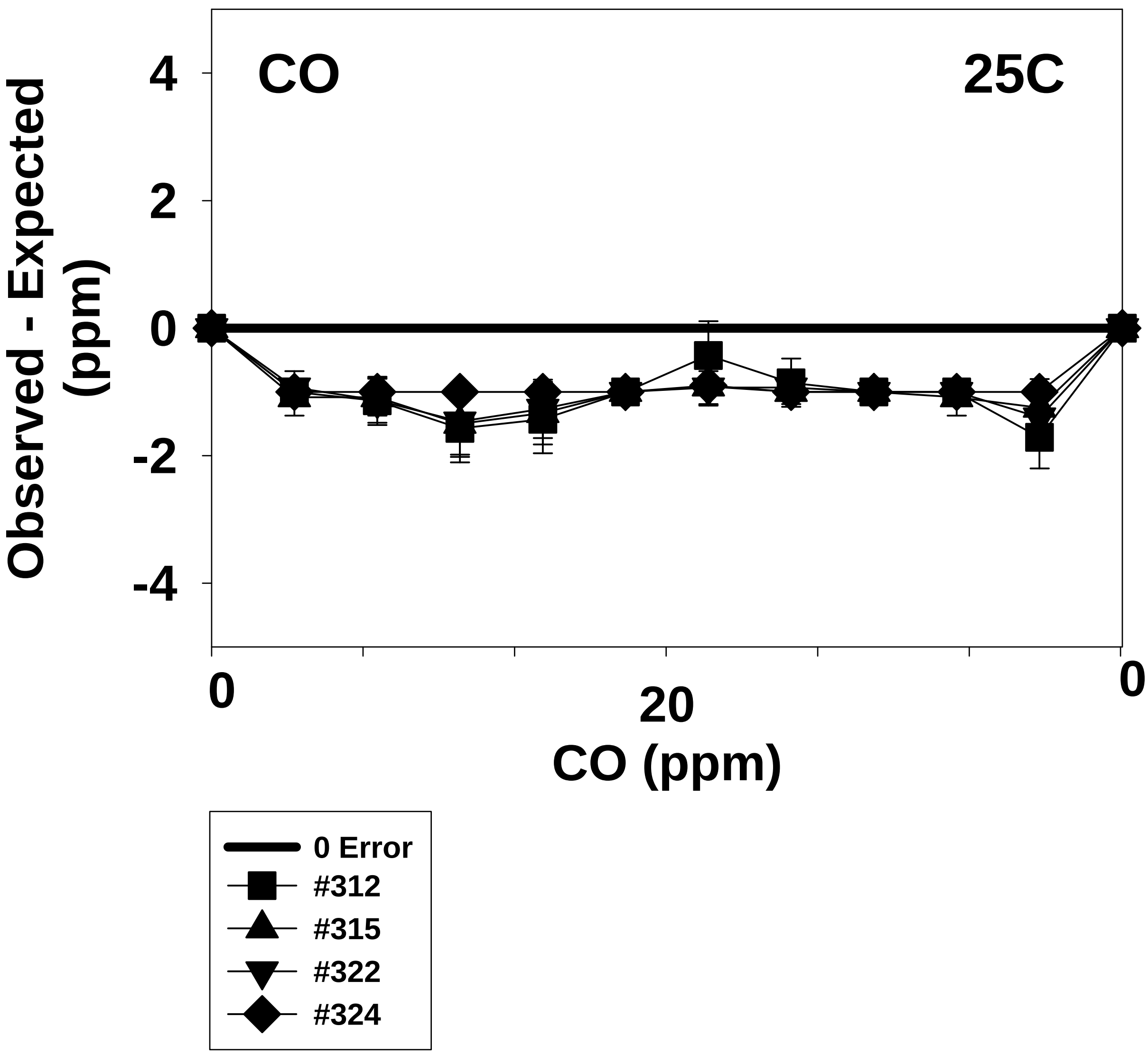


FIGURE 3B.
CO Accuracy: 42C
Means and SDs, N=3

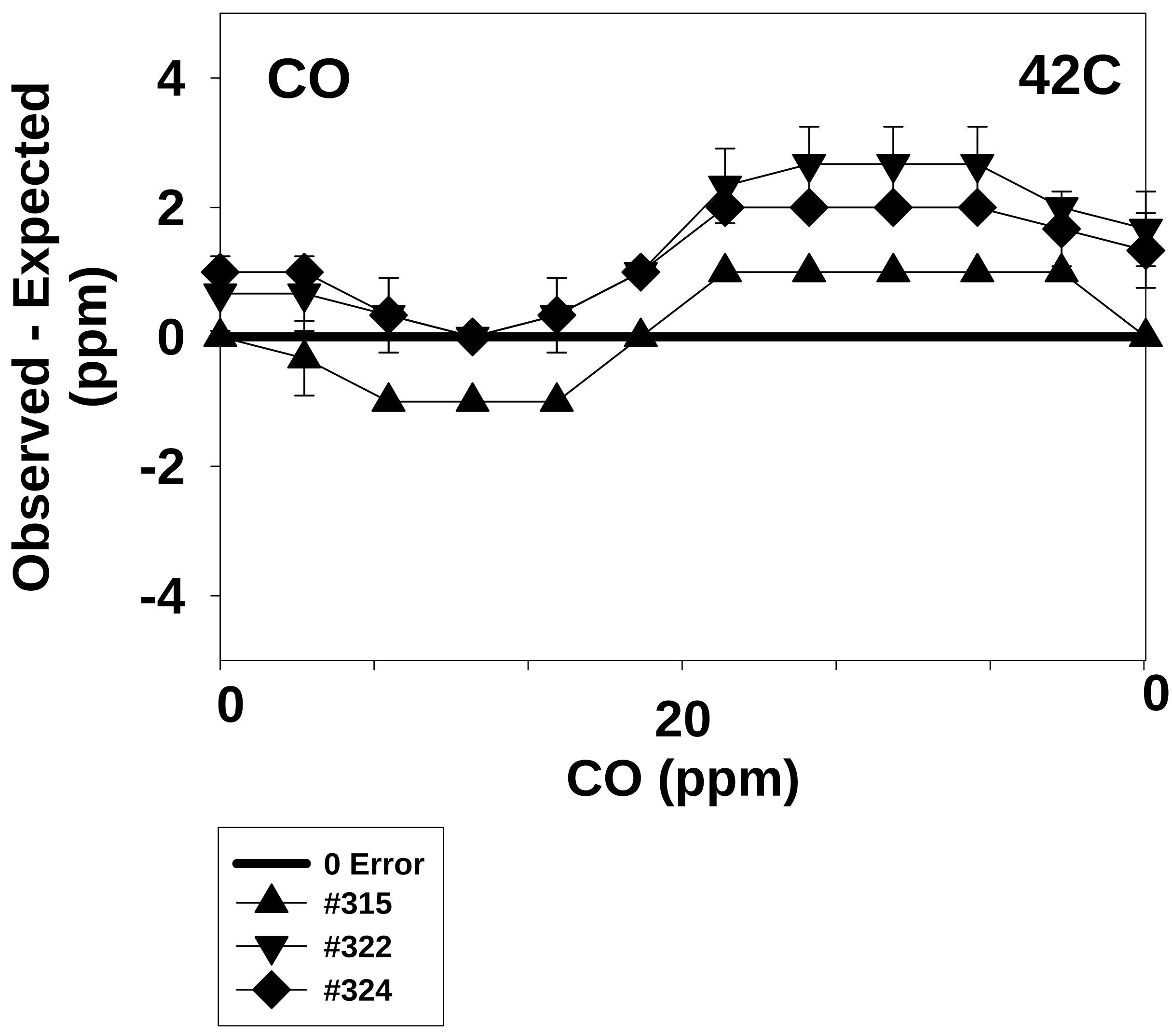


FIGURE 3C.
CO Accuracy: 5C
Means and SDs, N=2-3

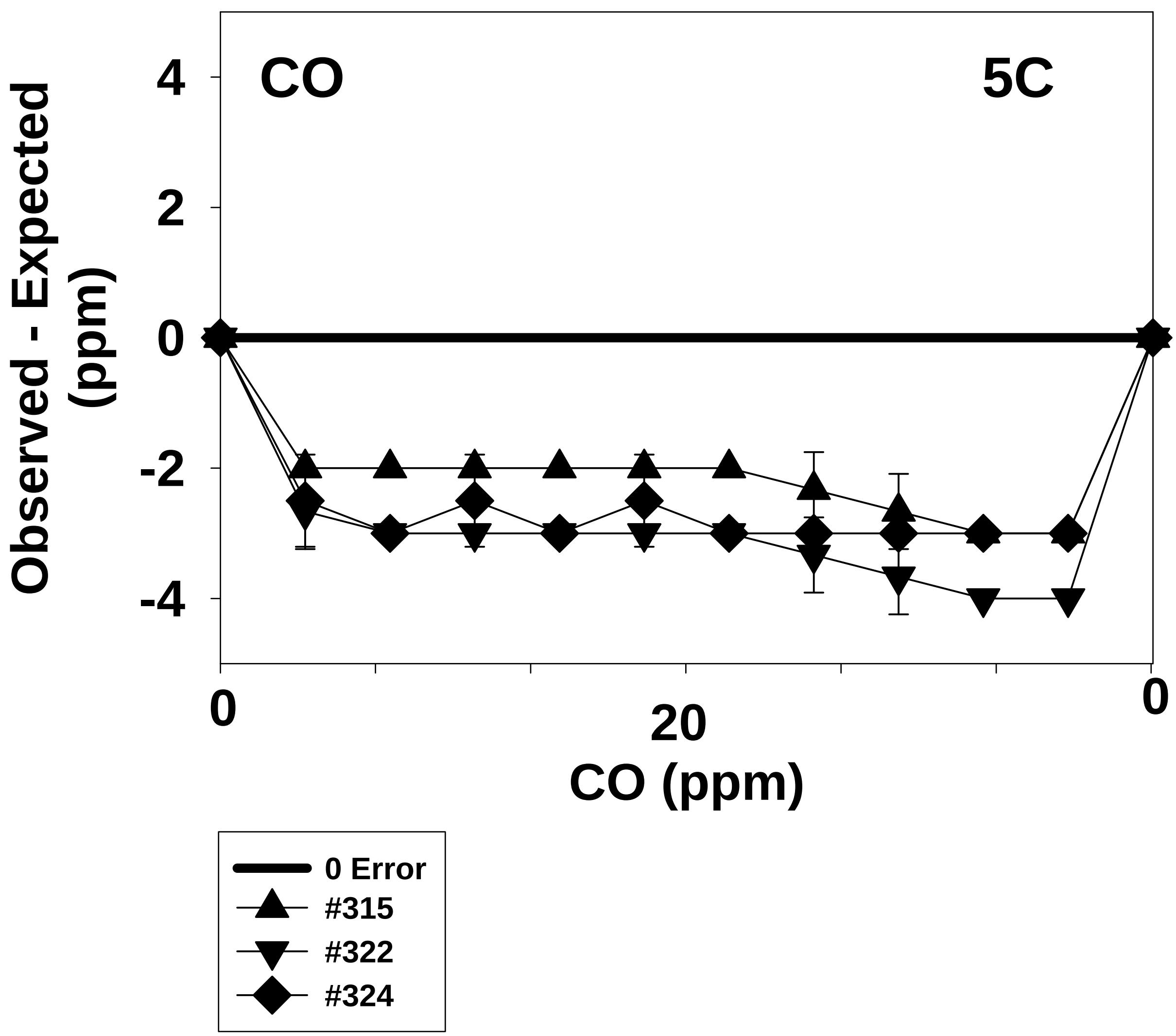


FIGURE 4A.
VOC Accuracy: 25C
Means and SDs, N=5-15

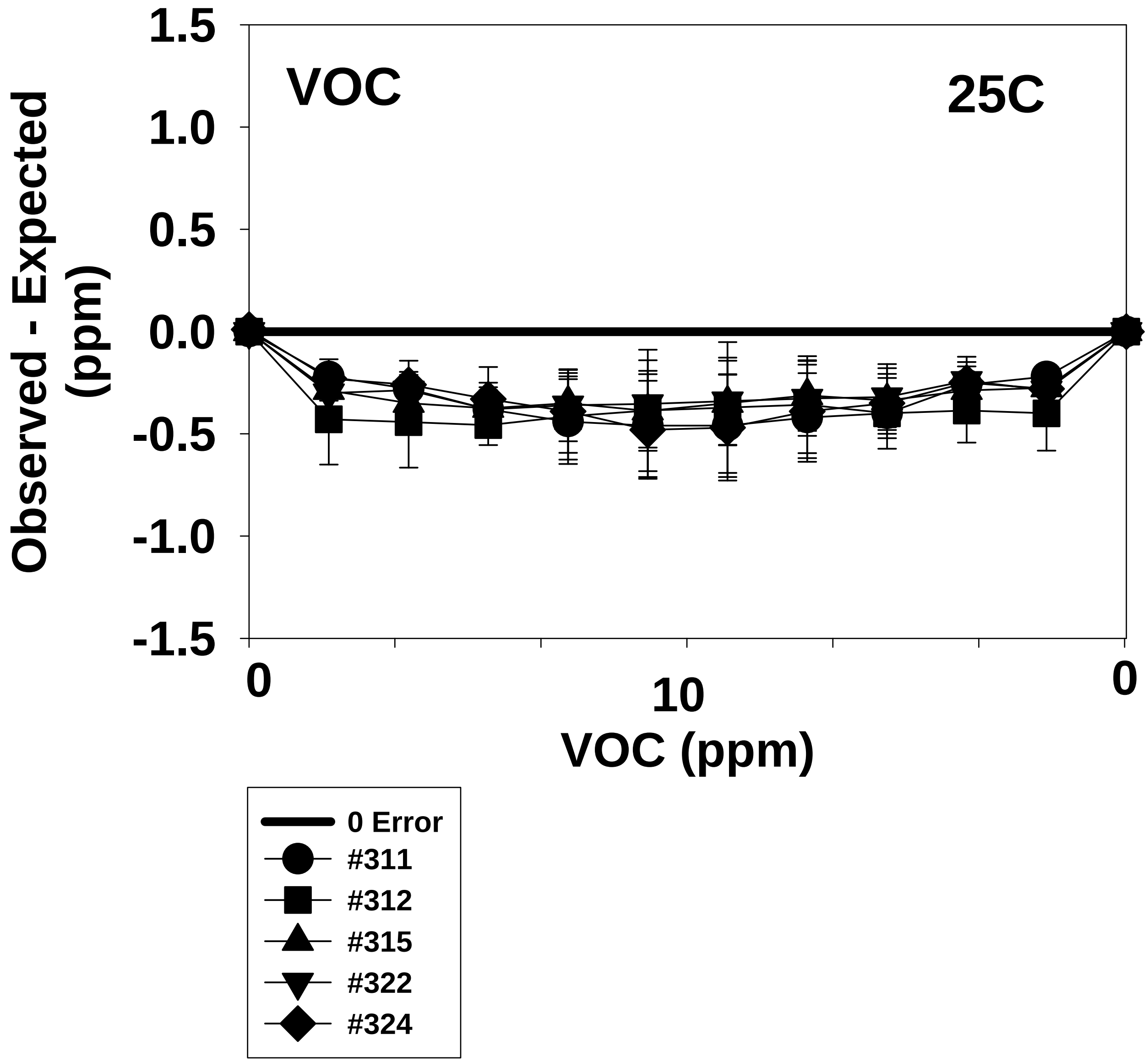


FIGURE 4B.
VOC Accuracy: 42C
Means and SDs, N=2-3

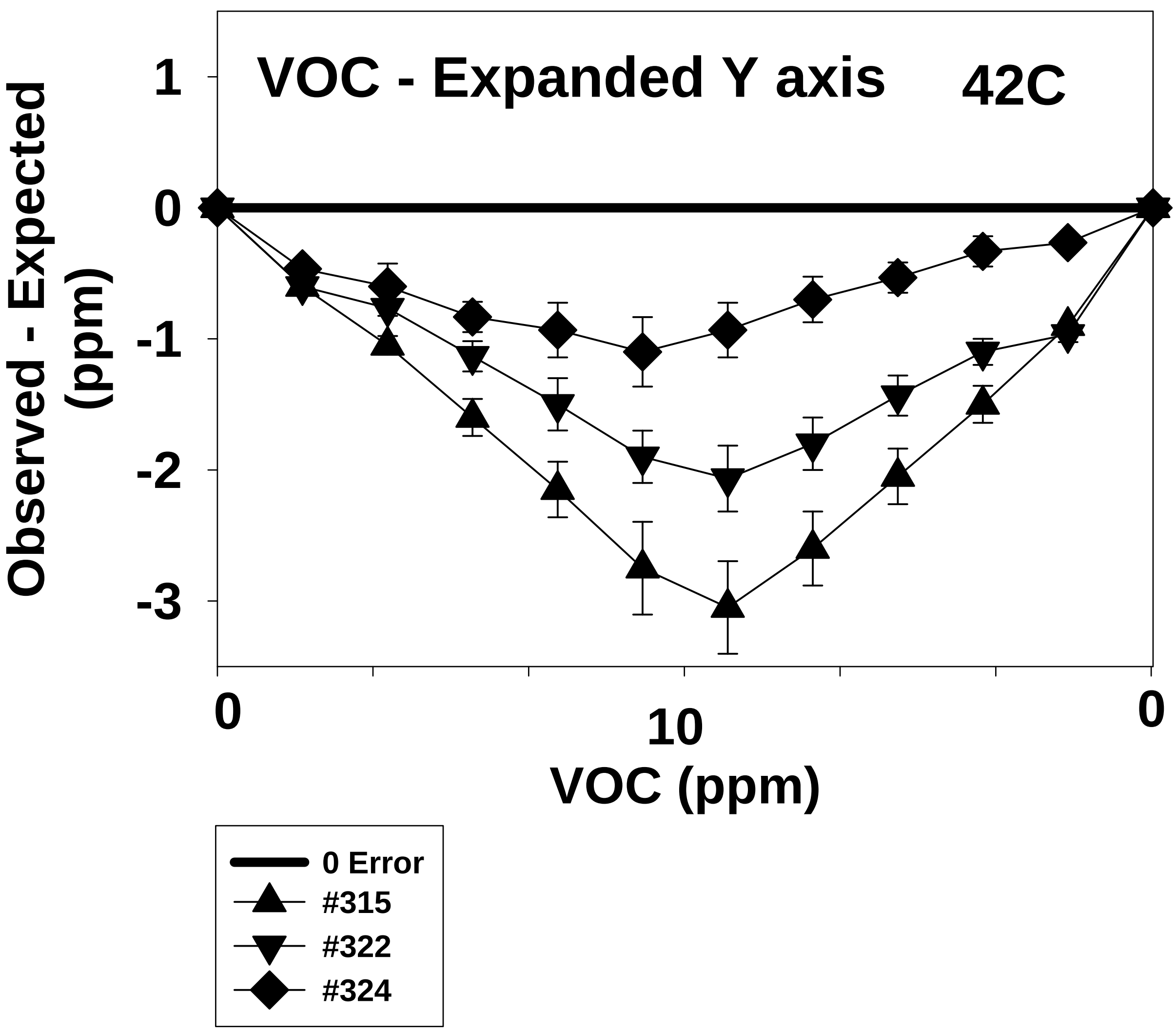


FIGURE 4C.
VOC Accuracy: 5C
Means and SDs, N=2-3

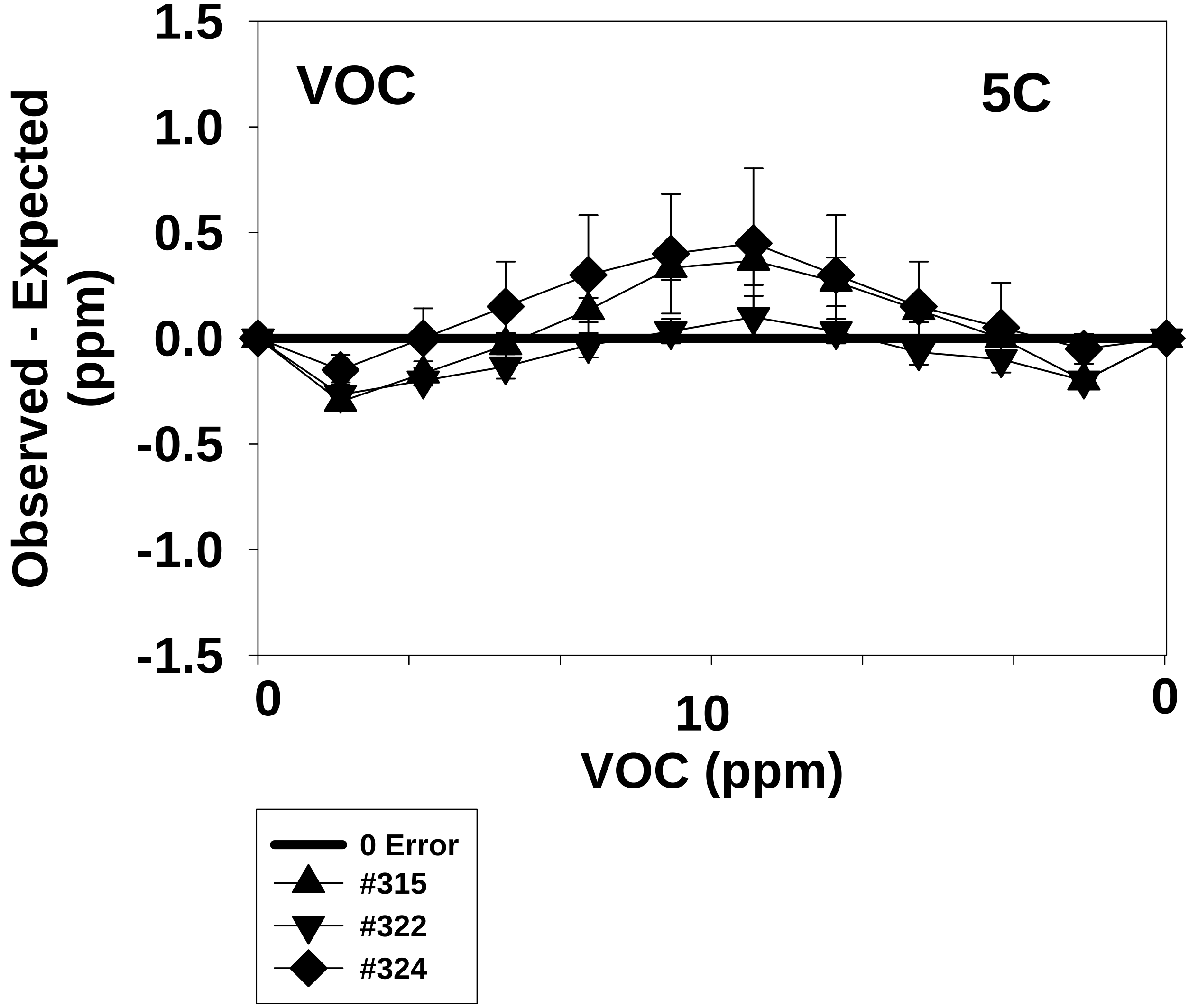


FIGURE 4D.
VOC Accuracy: 42C
<u>Final Prototype</u>
Means and SDs, N=2-8

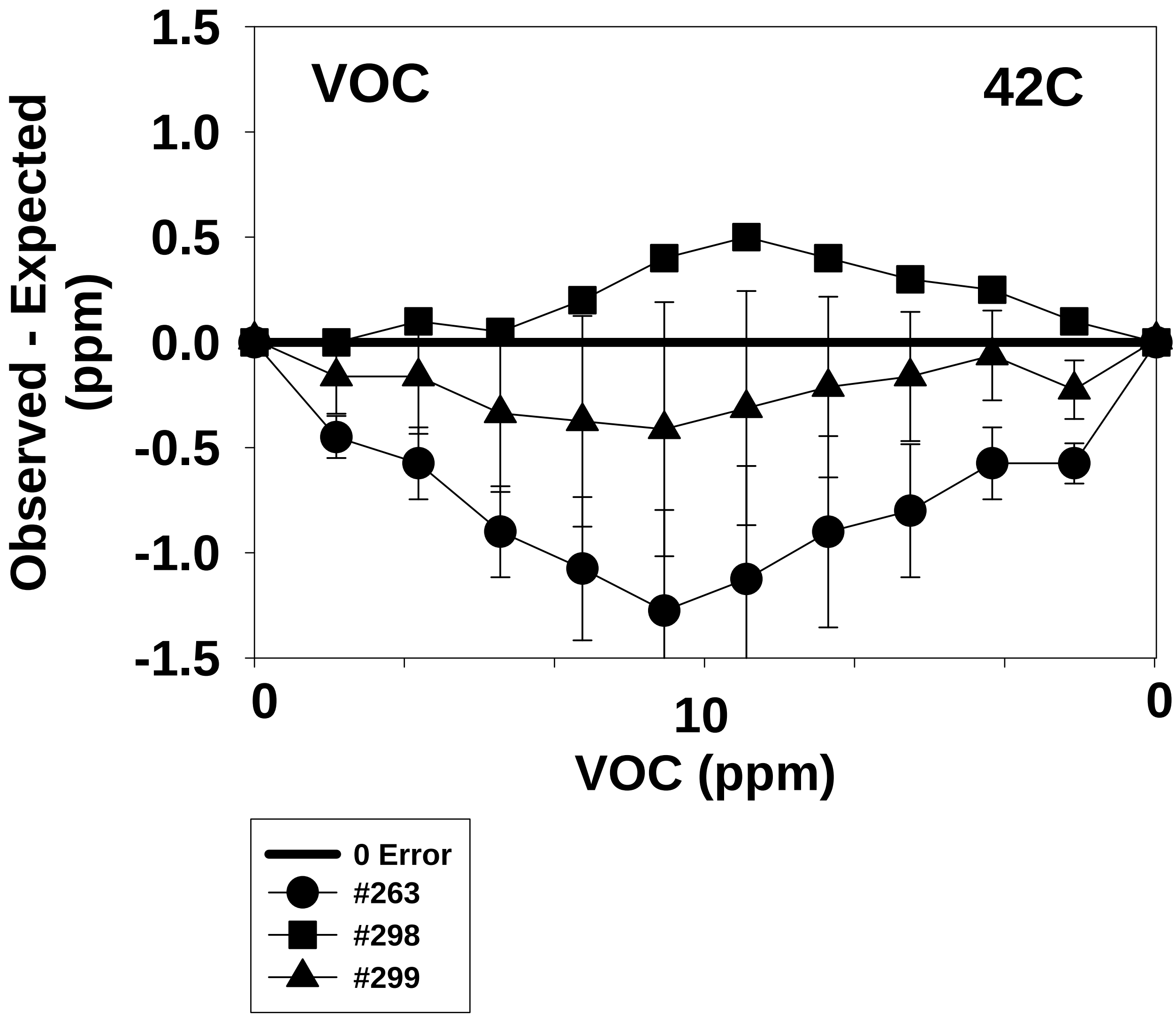


FIGURE 4E.
VOC Accuracy: 5C
<u>Final Prototype</u>
Means and SDs, N=2-7

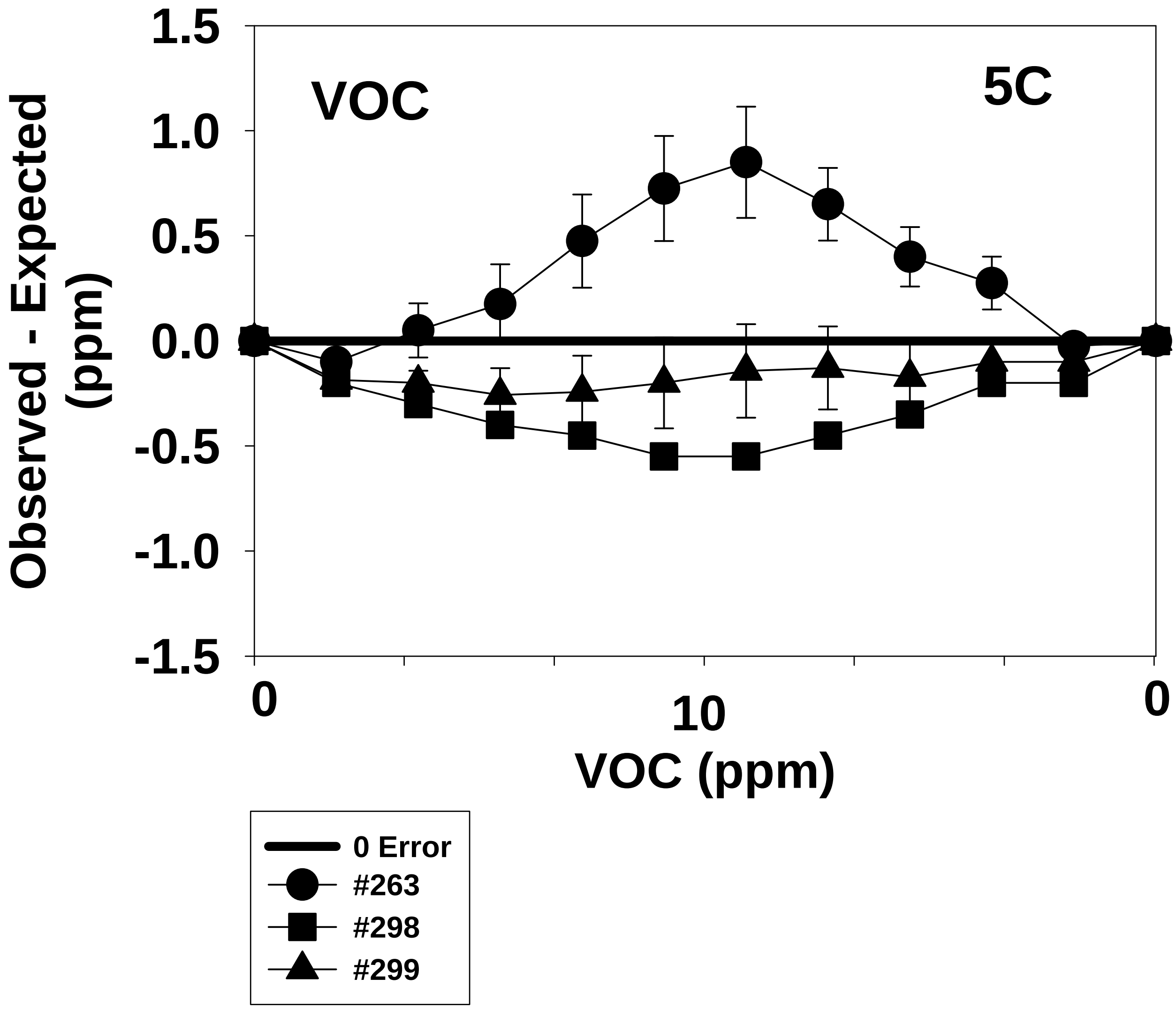


FIGURE 5A.
O2 Short-term Stability: 25C
Means and SDs, N=5-9

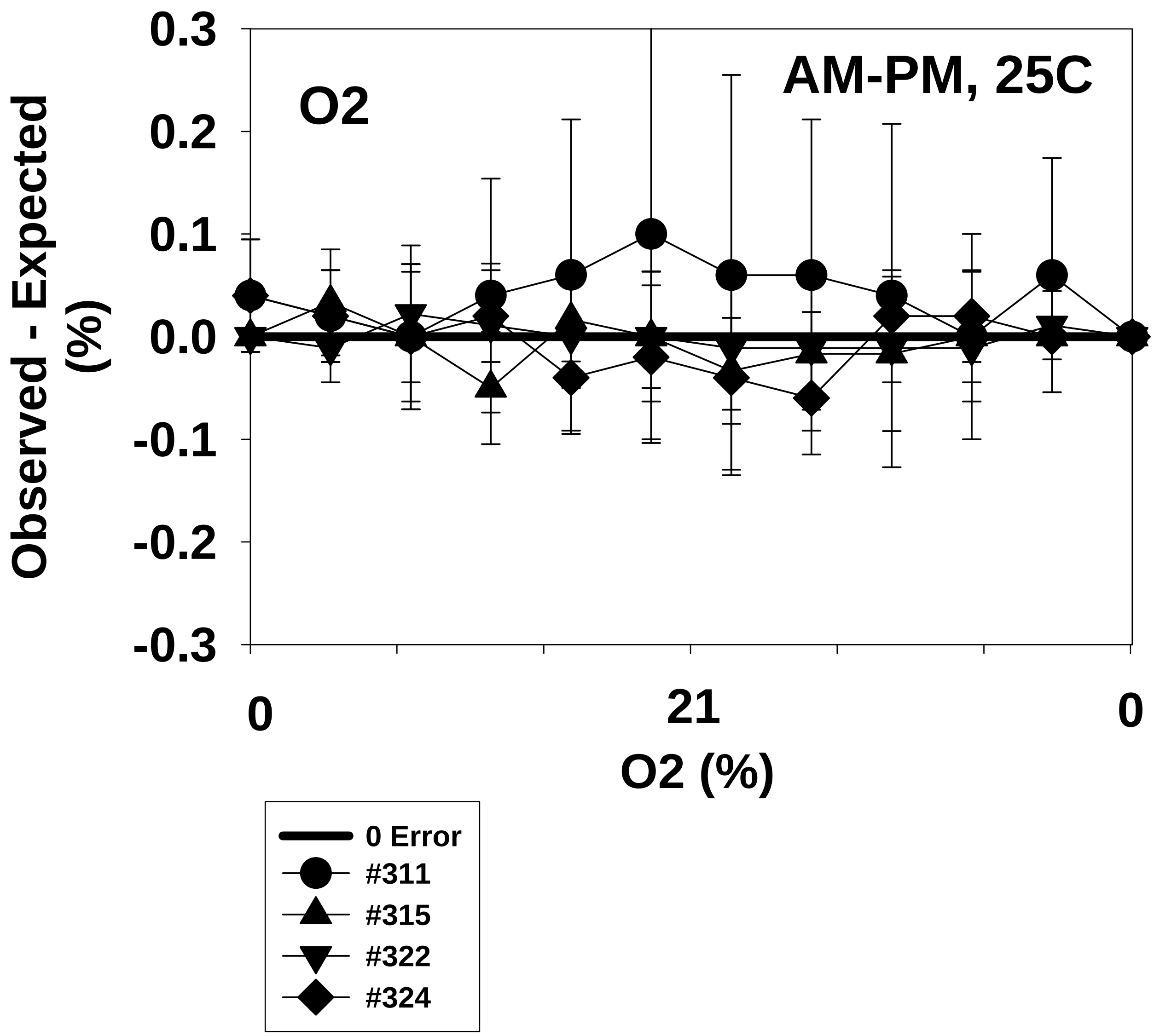


FIGURE 5B.
CO2 Short-term Stability: 25C
Means and SDs, N=5-9

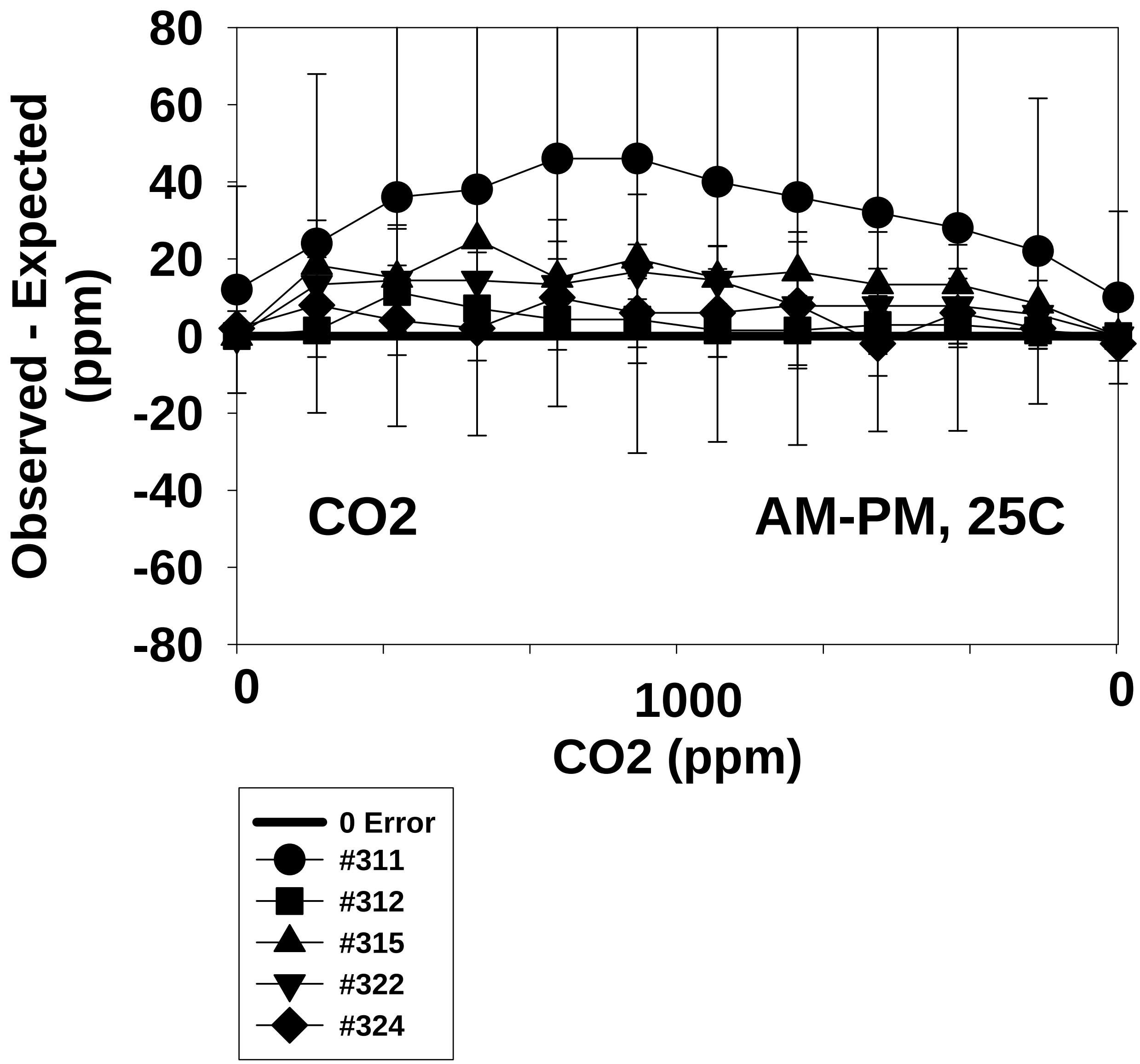


FIGURE 5C.
CO Short-term Stability: 25C
Means and SDs, N=5-9

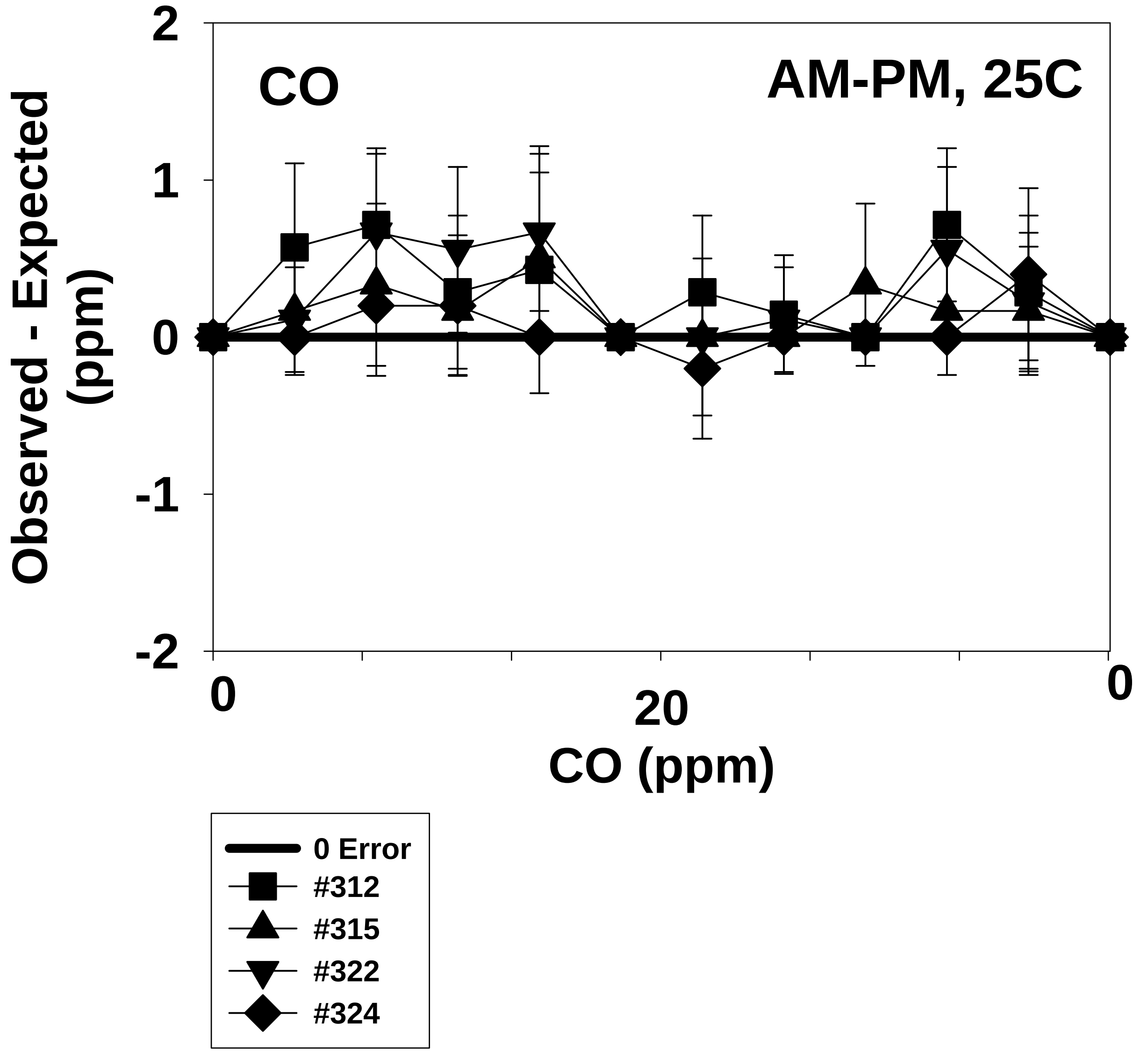
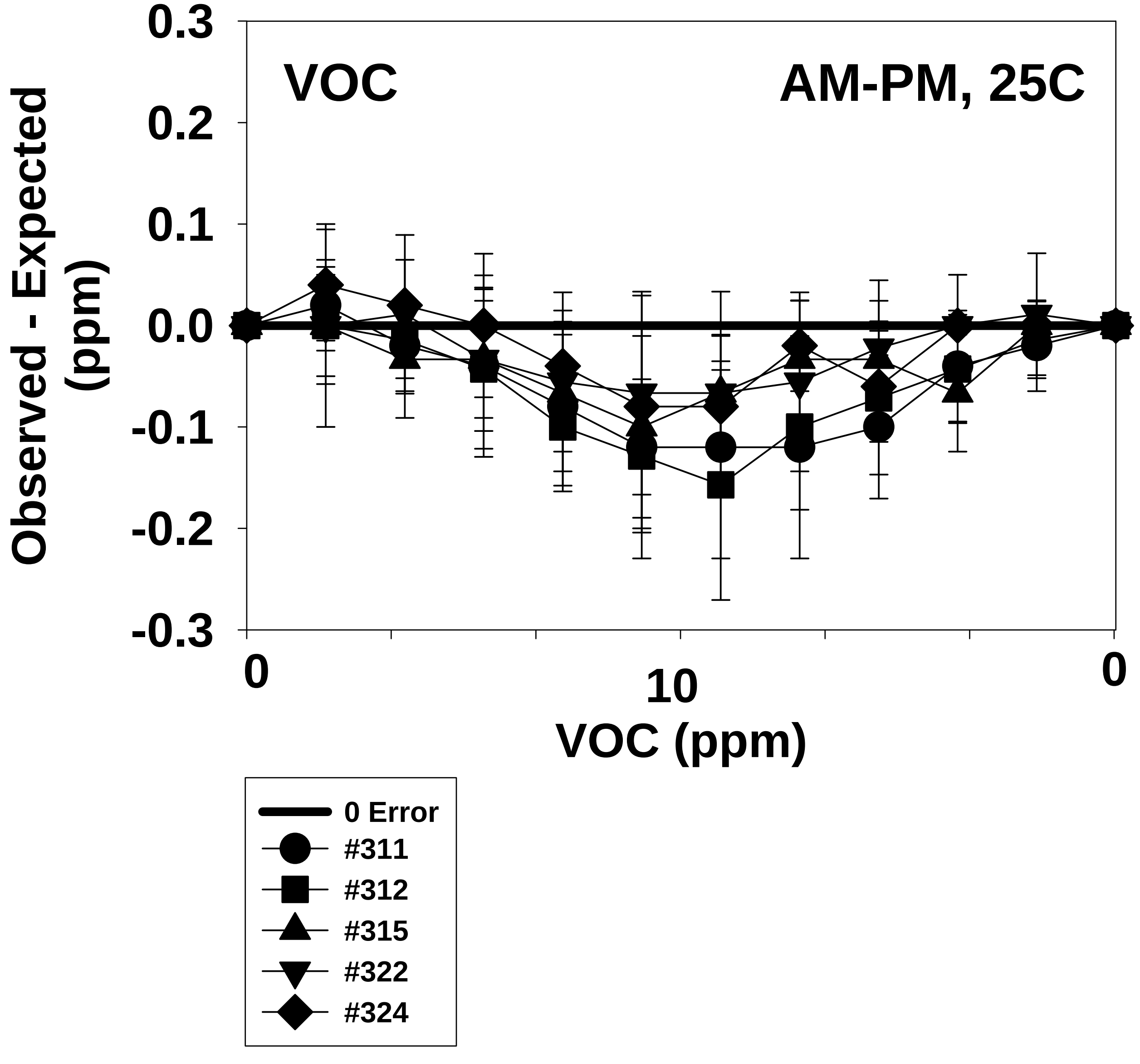


FIGURE 5D.
VOC Short-term Stability: 25C
Means and SDs, N=3-9



APPENDIX A

OPERATING PROCEDURES FOR THE NEDU AIR SAMPLING KIT (VERSION 1.0 OP-ASK)

Using version 1.0 ASK of the NEDU air sampling kit

This document provides information for calibrating the Diveair2 and using the monitor (with its sampling pump OFF) with the NEDU air sampling kit (version 1.0 ASK) to measure the quality of diving air. Since differences in gas delivery procedures and sampling hardware may significantly affect monitor performance, alternative operating procedures used in the laboratory or in the field will first need to be verified as producing acceptable results. NEDU has not evaluated the Diveair2 for screening gases other than air.

The Diveair2 monitor and NEDU air sampling kit allow screening of diving air for O_2, CO_2, CO, and volatile organic compounds (VOCs; including hydrocarbons) from the following:

1) Compressors and air banks.

2) Scuba bottles that have already been charged.

3) The Navy's Lightweight Dive System (LWDS), both during and following charging.

4) The Navy's Fly-Away Dive System (FADS), both during and following charging.

In addition, the monitor (with its sampling pump ON) can be used alone to test the ambient air quality at a diving site where such air may be suspect (e.g., at fuel-laden accident sites) prior to startup of a compressor system and use of the air for diving.

A. AIR SAMPLING KIT

The complete air sampling kit is contained in one "Pelican type" case and is designed to be capable of being shipped by air (FedEx and military transport).

SAMPLING COMPONENTS

The individual components of each kit include the following:

1. Two calibration gas cylinders — each of which is a refillable aluminum high-pressure container with an outside diameter of ~4.5 inches and a height of ~15 inches that, when full at ~2000 psig, holds ~115 liters of gas:

1) One cylinder of ultra high-purity-grade N_2 (99.999% N_2), for zeroing the monitor's four sensors during calibration.

2) One cylinder of "span gas" — a certified standard with nominal concentrations of 21% O_2, 1000 ppm CO_2, 20 ppm CO, and 10 ppm isobutylene (used for VOC calibration), balance N_2, for spanning the sensors. (Note: The 10 ppm isobutylene gas is nontoxic and has a long history of safe use.)

2. One Diveair2 air monitor, with battery charger.

3. One pressure-reducing regulator ("reducer") to decrease the air sample pressure down to several psig and deliver air at ~150 mL/min to the air monitor. It includes (1) a "bleeder" valve on the HP side of the reducer to allow the upstream dead space to be purged, so that real-time air monitoring can be achieved, and (2) a 0–15 psi downstream pressure gauge to confirm that gas is being delivered to the reducer. The upstream fitting is a ¼-inch male A/N allowing the high-pressure (HP) sampling whip (item #4) to be attached. The downstream fitting is a hose barb allowing the regulator to be attached to the air monitor via Teflon tubing (item #5).

4. One HP microhose assembly ("HP sampling whip") to connect the HP air sampling hardware to the reducer. The 2.9 mm inner diameter (ID) of the 10 ft long sampling whip introduces ~20 mL of dead space volume into the sampling pathway. The inner hose is made of polyamide 11 (a nylon). Both ends of the whip contain ¼-inch female A/N fittings.

5. Teflon tubing with flexible PVC tubing ends to connect the air monitor to the reducer via hose barb fittings. The Teflon should ensure that the gas flowing through the delivery system minimally affects it, and this should be the only tubing used for this purpose. This tubing arrangement allows both calibration and sample gases to be delivered to the monitor.

6. HP sampling adaptors, all with downstream ¼-inch male A/N fittings to allow the HP sampling whip to be attached, include the following:

1) A scuba adaptor, to allow sampling air from scuba bottles that have already been charged.

2) A scuba charging adaptor, to allow air from the charging whip (attached to the scuba bottle) to be sampled at the point where that whip attaches to the bottle.

3) A LWDS adaptor, to allow air to be sampled both during and after charging of the LWDS.

4) A FADS adaptor, to allow air to be sampled from the FADS both during and after charging of the FADS.

7. CGA 580 calibration adaptor (Teflon-tipped and with handwheel), with a downstream ¼-inch male A/N fitting, to allow the N_2 gas cylinder to be attached to the reducer via the HP sampling whip during air monitor calibration.

8. CGA 590 calibration adaptor (Teflon-tipped and with handwheel), with a downstream ¼-inch male A/N fitting, to allow the span gas cylinder to be attached to the reducer via the HP sampling whip during air monitor calibration.

9. Pressure gauge (0 to 3000 psig) with ¼-inch female A/N fitting, to be attached to the CGA 580 and CGA 590 calibration adaptors to measure pressures of the two calibration gas cylinders and determine how much calibration gas is left.

10. Shipping instructions and required supporting documents, to facilitate shipping the air sampling kit by air.

11. Testing procedures document, to provide information for using the NEDU air sampling kit.

SAMPLING APPARATUS

The “sampling apparatus” stored in the top portion of the case housing the air sampling kit is used to calibrate the air monitor and sample the diving air. This apparatus includes the following components mounted on a panel of plastic for ease of use and transport during calibration and air sampling: a reducer, an air monitor with attached Teflon tubing connected to the reducer, and the two calibration gas bottles. The remaining hardware of the sampling kit (items #4 and #6 through #9 described above, and the battery charger) is stored in the bottom portion of the case, where a layer of foam padding separates it from the sampling apparatus. Required shipping documents and testing procedures (components #10–#11) are in an envelope stored under the foam padding lining the top cover of the case. When necessary, the calibration gas cylinders can be easily removed from the sampling apparatus and replaced, and the monitor can be removed quickly to allow battery charging and data downloading (if desired) at a convenient site.

For startup and calibration of the monitor, the sampling apparatus is removed from the kit and laid horizontally on a workbench or equivalent site to facilitate completing the required procedures. When these initial steps have been completed, the sampling apparatus and kit are moved to a convenient sampling location. There the appropriate hardware from the kit is used to attach the apparatus to the air source to be sampled, and the apparatus is laid horizontally or set upright as desired.

B. GENERAL PROCEDURES

1. When testing is not being done, and whenever possible, the air monitor and all testing gear should be stored indoors (at temperatures ranging between 19 and 25 ºC [66–77 ºF], "normal room temperature") and thus protected from inclement weather.

2. The acceptable range in ambient temperatures for operating the air monitor is from 0 to 50 ºC (32 to 122 ºC). However, despite the monitor's incorporation of corrections to gas readings for changes in ambient temperature, the accuracy of gas readings will be greatest at temperatures closest to normal room temperatures (again, between 19 and 25 ºC [66–77 ºF]) at which calibration will normally be done. Thus, when using the air monitor at the extremes of its acceptable operating range, unexplained or suspect gas readings may be due at least in part to the effect of temperature.

3. Although the air monitor has a datalogging capability that was used extensively during laboratory testing and evaluation of the monitor, no datalogging will be performed during testing. The Navy is unsure whether datalogging is a desired function for normal air sampling in the Fleet.

4. The two-page data sheet at the end of this document is designed so that, after completing several days of testing, testers may be able to perform continued testing by following the data sheet with minimal help from the written procedures in this document. We also expect that initial checks of the monitor settings and of its status during startup and calibration will be quickly completed after testers have acquired a little experience in using the monitor.

MONITOR BATTERIES/CHARGING

1. The Diveair2 is expected to be normally operated with power from its self-contained nickel metal hydride battery. When this battery requires charging, the monitor is attached to the charger, which plugs into 110-volt line current. (To allow charging in some foreign countries with different electrical standards, additional electrical plug adaptors are supplied with the charger.) However, since the charging process can affect gas readings, *the monitor should not be used while it is connected to the battery charger*. An optional ~10 m power cord (not a charger, and not supplied with the current air sampling kit) is designed for use in wet environments and allows the monitor to be operated with or without batteries.

2. Limited laboratory testing shows that fully charged batteries provide approximately 14 to 16 hours of monitor use with the sampling pump ON, and that full recharging takes three to four hours. Experience will show how long monitors can be operated between recharging times in the field with the pump OFF (as it will be used for sampling diving air) and how long recharging takes under field conditions.

3. When the monitor is not in use, it can be removed from the sampling apparatus and left attached to the battery charger in a safe place. However, if the monitor is used infrequently and simply left on the charger, its battery capacity may diminish. If this capacity is reduced, to help restore that capacity, the battery should first be completely discharged by operating the monitor until it shuts off; then it should be recharged. As an alternative after the battery has been charged, the monitor can be stored in the air sampling kit for short times between use. For now, we anticipate that monitors can be stored in the air sampling kit and not on the charger for up to least two weeks before the next testing. But again, experience will show whether this storage time can be extended under field conditions.

C. MONITOR STARTUP AND CALIBRATION
(Conserve Calibration Gas)

1. If necessary, move the air sampling kit to where calibration will be done. If possible, this location should be indoors, protected from inclement weather, and at temperatures similar to those where the sampling kit has been stored (again, between 19 and 25 ºC (66–77 ºF).

2. Open the air sampling kit, remove the sampling apparatus, and lay the apparatus horizontally on a workbench, or an equivalent, to facilitate its startup and calibration.

3. If the monitor has not been stored in the air sampling kit, locate the monitor and, if it is connected to the charger, disconnect it and bring the monitor to this calibration location. Attach the monitor to the sampling apparatus and then attach the Teflon tubing to the monitor, but do NOT attach the Teflon tubing to the reducer.

4. If the monitor is already attached to the sampling apparatus, DISCONNECT the Teflon tubing from the reducer and confirm that the Teflon tubing is connected to the monitor.

5. Use the data sheet at the end of this Appendix to record information during the test. **Complete** the top two lines on the first page of the data sheet, including the monitor serial number (S/N) and air sampling kit's S/N. **Record** any comments related to startup and calibration at the bottom of the sheet; if necessary, also use the back of the sheet.

6. Turn the monitor ON by pressing the red key. Press "0" to exit that screen. Press "5" to turn the pump ON and flush the monitor of any residual contaminants during the warm-up period; the "Pump" text appearing in bold and the pump noise confirm that the pump is turned on. **Record** the startup time.

7. Before each day's use of the monitor, the batteries need to be checked as follows:

1) Wait 5 min for the monitor to warm up, and then press "9" to read and **record** the available battery capacity, a reading that should be 100%. If readings are less

than 80% after the batteries have been recharged at least overnight, the batteries may need to be replaced. However, readings may be “low” if the monitor has been stored inside the sampling kit.

2) Press “0” to return to the monitoring display. Again, confirm that the pump is ON.

8. Determine whether the monitor needs to be calibrated.

<u>Daily calibration is recommended, IF the following applies</u>: Under conditions such as when the monitor and sampling kit are being moved about during testing (e.g., when testing is done on diving trailers and boats, or at pierside) and when ambient temperatures during testing are often not controlled, the monitor should be calibrated before each day’s use.

<u>Weekly calibration allowed</u>. For indoor air testing (when the testing gear remains inside at one test site, the ambient temperature is controlled, and the monitor and sampling kit are moved little following the monitor’s calibration), the monitor needs to be calibrated before use only if more than a week has passed since its last calibration — OR if gas readings during testing suggest that it may be out of calibration.

<u>Uncertain history: calibration recommended</u>. Data sheets from past testing may help decide whether calibration is necessary before use. However, if the date the monitor was last calibrated, or the monitor’s history, or the status of the monitor’s passcode-protected settings are uncertain, *the monitor should be calibrated before it is used*.

9. <u>If the monitor does NOT need to be calibrated</u>, **record** the date of its last calibration, and <u>ensure that it has warmed up for at least 20 min before skipping to step #38 below</u>.

10. <u>If the monitor needs to be calibrated</u>, **record** both the cal gas cylinder S/Ns and the span gas concentrations on the data sheet.

11. Access the passcode-protected menus to perform the functions (below) that are related to alarms and calibration. To enter the passcode, first press “1-menu,” then “0,” “1,” “0,” and “2” (the passcode Geotechnical Instruments has set for all monitors) — followed by a final “0.”

12. Alarm settings. Visual alarms occur when a gas level is outside the range specified for the alarm levels. The alarms include both a flashing external alarm light that can be seen at a distance from all directions and a displayed blinking of the name(s) of the alarming gas(es).

1) Check the alarm settings stored in the monitor by pressing “2–Alarm Settings.”

2) Check that the alarm latching is OFF for calibration. If necessary, change this setting by pressing “1,” so that if any of the alarms are triggered, they will stop once the gas concentrations are acceptable.

3) Check the alarm levels by pressing “2” and, to avoid triggering the alarms, ensure that the following calibration levels are set: O_2 less than 00.0%, CO_2 greater than 5000 ppm, CO greater than 100 ppm, and VOCs greater than 50.0 ppm. If changes are needed, first press the number of the gas (e.g., “1” to change the O_2 value), and then enter the alarm level, followed by “0.” When numeric data is being entered, holding down the “0” key will act as a backspace and erase the last digit entered.

4) When all gas values are correctly set, press “0” twice to return to the function screen.

13. Span gas settings.

1) Check the span gas concentrations stored in the monitor by pressing “1–Calibration” and then “4–Check/Set gases.”

2) If necessary, change the span gas concentrations to the actual concentrations of gas being used (e.g., 21.0% O_2, 0980 or 1010 ppm CO_2, 020 ppm CO, 10.1 ppm VOC) by first pressing the number of the gas (e.g., “1” to change the O_2 value) and then entering the span gas concentration followed by “0.” VOC in this case is the concentration of the isobutylene. (Note: It may be convenient to write the span gas concentrations on a tag to be attached to the cylinder’s valve. Before the tag is prepared, verify that the label on the side of the span gas cylinder agrees with information on any gas cylinder certificate supplied with the gas sampling kit; when such agreement is doubtful, rely on certificate concentration levels.)

3) When all gas concentrations are correctly set, press “0” three times to return to the monitoring display. Again, confirm that the pump is ON.

14. **Record** that alarm settings and span gas concentrations have been entered into the monitor.

15. Blow out both the N_2 and the span gas cylinder valves with minimal gas (less than a 1-second purge), and install the CGA 580 adapter onto the N_2 cylinder and the CGA 590 adapter onto the span gas cylinder.

16. Attach the pressure gauge to one of the gas cylinders and check it for leaks by quickly opening and closing the cylinder valve to confirm little or no pressure decrease over 1 min. Tighten or adjust the adapter until any leak is corrected. Then open the valve and **record** the cylinder pressure; close the valve and remove pressure gauge.

17. Repeat the leak check and **record** the pressure reading for the other cylinder.

18. Ensure that the monitor has warmed up for at least 20 min before proceeding with step #19.

19. TURN OFF the pump by first confirming that the monitor is in the monitoring mode and then pressing "5" to stop the pump. **Record** the time the pump is turned off.

20. **Record** where indicated on the data sheet the calibration information (along with any comments), while following the calibration procedures in steps 21–37 below:

21. Connect the HP whip to the N_2, blow out the whip with minimal gas (less than a 1-second purge), shut off the gas, and then attach the whip to the reducer. Ensure the bleeder valve on the reducer is closed. Then open the N_2 valve and, carefully using "snoop" (or an equivalent) to check for leaks at both ends of the whip, AVOID getting the hardware saturated with liquid. Correct any significant leaks.

NOTE: A reading of ~3 psig on the reducer's downstream pressure gauge will confirm that pressure has been delivered to the reducer — although the reducer's downstream pressure gauge is not meant to provide accurate and precise readings and has been observed to experience zero shifts. However, if blockage is suspected and reducer flow needs to be confirmed, a quick manual blockage test of the reducer's outlet just before the monitor is used may be valuable. This downstream gauge should show a slight pressure increase (~0.5 psig) when the reducer outlet is manually blocked with a finger.

22. Attach the Teflon tubing to the reducer, and **record** the "start gas" time to ensure that at least 5 min is allowed for N_2 readings to equilibrate.

23. Observe the monitor gas values until they are stable (at least 5 min), and then r**ecord** the N_2 readings. This information will help judge the stability of the calibration since the monitor was last used.

24. While continuing to sample N_2 gas, zero all channels by pressing "1–Menu"; "0,1,0,2" followed by "0"; "1–Calibration"; "1–Zero channels"; and "1–yes." Note the outcome (okay or failed). A failed response may indicate a problem that needs to be corrected, but a rezeroing should first be tried.

25. Press "0" twice to return to the monitoring display, and **record** the time the monitor was zeroed and the postzero N_2 readings. Readings should be no greater than 0.2% O_2, 40 ppm CO_2, 2 ppm CO, and 0.2 ppm VOC. If any reading is greater than these values, rezero the monitor and again **record** the rezeroing time and the gas readings on the data sheet alongside the first set of readings (first reading/second reading). Then proceed to the next step, even if any reading is still greater than the limits specified here.

26. Disconnect the Teflon tubing from the reducer and then shut off the N_2 valve.

27. Open the bleeder valve on the reducer to depressurize the whip, and then disconnect the HP whip from the N_2. Close the bleeder valve.

28. Reconnect the HP whip to the span gas, blow out the whip with minimal gas (less than a 1-second purge) through the bleeder valve, and then shut off the gas and bleeder valve. Open the span gas valve and, using “snoop,” check for leaks at the gas cylinder side of the whip. Correct any significant leaks.

29. Attach the Teflon tubing to the reducer, and again **record** the “start gas” time.

30. Observe the values until they are stable (at least 5 min), and then **record** the span readings before spanning.

31. Span all channels while continuing to sample span gas by pressing “1–Menu”; “0,1,0,2” followed by “0”; ”1–Calibration”; “2–Span channels”; and “1–yes.” Note the outcome (okay or failed). Again, a failed response may indicate a problem that needs to be corrected, but a respanning should first be tried.

32. Press “0” twice to return to the monitoring display, and **record** both the time the monitor was spanned and the postspan values. Readings should be within 0.2% O_2, 40 ppm CO_2, 2 ppm CO, and 0.2 ppm VOC of the span gas values. If any gas reading is outside these ranges, respan the monitor and **record** the respanning time and the gas readings again alongside the earlier data. Proceed to the next step, even if any reading is still outside the respective ranges specified here.

33. To verify that alarms are operating correctly, check them via the following procedure:

1) Continue to sample span gas.

2) Change the alarm levels by pressing “1–Menu”; “0,1,0,2” followed by “0”; and then “2–Alarm Settings.” Press “2–Alarm levels” and change the settings to O_2 less than 20.0%, CO_2 greater than 1000 ppm, CO greater than 020 ppm, and VOCs greater than 10.0 ppm. These settings should trigger the alarms if any gas is outside the specified limit, per the *Navy Diving Manual*.

3) With the alarm latching OFF (as checked earlier), any triggered alarms will stop once the gas concentrations are acceptable.

4) Return to the monitoring mode by pressing “0” three times. Note that the variations in the monitor’s readings may cause one or more of the gases to go into and out of the alarm mode. However, if no alarms are triggered, change the CO_2 alarm setting to 900 ppm to trigger the CO2 alarm.

5) If required, return the CO_2 alarm setting to 1000 ppm.

6) **Record** the alarm function as “pass” or “fail.”

34. Disconnect the Teflon tubing from the reducer, and shut off the span gas valve.

35. Disconnect the HP whip from the reducer, allow the whip to depressurize, and then disconnect the whip from the span gas.

36. Remove both CGA adapters from the gas cylinders and, after drying everything off, replace all loose hardware into the sampling kit. Leave the sampling apparatus out and the attached monitor turned ON.

37. Press “5” to turn the pump ON and flush out the span gas. **Record** the time that the pump was turned on.

38. If the monitor is being used to screen ambient air quality, go to s**ection G, AMBIENT AIR MONITORING**, below.

39. Move the sampling apparatus and sampling kit to the sampling location.

40. **Complete** the top third of the second page of the data sheet: on the basis of what is being sampled, **fill in** the appropriate information about the air source. Use the back of the sheet (if necessary) to **record** additional comments related to testing.

41. Go to the appropriate section below for testing <u>either</u>

1) the quality of the compressor discharge air or that of the gas in the air banks or flasks during charging or other operations (**section D**), <u>or</u>

2) the quality of the air in previously charged scuba bottles, or the air quality during or following charging of the LWDS or FADS (**section E**).

D. TESTING COMPRESSORS OR AIR BANKS (during charging or other operations)

SAMPLING SITE

1. <u>Preferred site</u>. The preferred method of testing the discharge air from compressors or air contained in flasks or banks is to use the HP sampling whip from the sampling kit to sample the gas from a connection on the existing piping of either system. For compressors, the HP sampling whip is attached to allow air to be sampled as close as possible to the compressor but downstream from all filters and the moisture separator, per the *U.S. Navy Diving Manual*.[1] To allow real-time monitoring, this compressor

sample location should ideally extend in a T-shaped alignment from the flowing compressor discharge. Similarly, to help ensure reliable gas sampling for air banks, the sampling site should minimize the dead space between the air bank and the point where the HP sampling whip is attached. However, this method assumes that, for compressors and air banks, an appropriate site where the ¼-inch female A/N connection of the sampling whip can be attached is available — or, if needed, an additional adaptor fitting (not supplied in the kit) can make the connection to the ¼-inch A/N.

2. Alternative site. If the compressor or air bank has no suitable connecting point at the preferred site or if adaptor fittings to make the connection to the HP sampling whip are unavailable, then the alternative is to sample from the downstream end of a scuba charging whip connected to a scuba bottle, as described in the following **Procedures** subsection.

PROCEDURES

1. For compressors ONLY. Before any compressor is sampled, it should be operated for at least 30 minutes to warm up, with the compressor start-up time **recorded**.

2. For all sampling. If possible, before the HP sampling whip is attached, either blow air through the sample site where HP sampling whip will be directly attached or, alternatively, blow air through the scuba charging whip. Such purging should be at a highly audible rate to equilibrate the line with the gas, with at least 10 times the estimated dead space volume of gas upstream to the compressor discharge or air source. When purging has been completed, shut off the flow.

3a. For a direct connection of the sampling whip ONLY. If a connection is made directly to the compressor or air bank (and NOT with a scuba charging whip), one end of the HP sampling whip should be attached from the air sampling kit to the sample site. An "O_2-cleaned" fitting (if needed and available, but not supplied in the kit) can be used to make the connection. If such an O_2-cleaned fitting is unavailable, a "visibly clean" fitting can be substituted after a heat gun or equivalent has first been used to heat the fitting to a level "just hot to touch" and the fitting is then allowed to cool before use. This heating procedure will encourage any residual VOCs to offgas and be eliminated from the fitting.

3b. For a sampling from the end of the scuba charging whip ONLY. Attach the scuba charging adaptor from the sampling kit to a scuba bottle. Then, following standard procedures to prepare for charging, attach the charging whip from the air source to the charging adaptor. Finally, attach one end of the HP sampling whip from the air sampling kit to the A/N fitting of the charging adaptor. Regardless of whether any scuba bottles are actually charged, this testing arrangement should be considered a convenient way to sample the air source when the sampling whip cannot be attached directly. In fact, since a scuba bottle requires a relatively short charging time and 5 minutes are required for monitor gas readings to equilibrate, *this testing is not designed to specifically check*

the small amount of air that is charged into any one scuba bottle. Air from previously charged scuba bottles can tested with other procedures presented in Section E below.

4. Blow gas from the compressor or air bank out of the HP sampling whip for 10 seconds. Then shut off the gas and attach the other end of the HP whip to the reducer WITHOUT the Teflon tubing attached to the reducer. Ensure the bleeder valve on the reducer is closed.

5. Open the appropriate valve(s) to deliver sample air to the reducer, and use "snoop" at all connections to check for leaks, especially at both ends of the sampling whip. Correct any significant leaks. The reducer should deliver sample gas to the monitor at ~150 mL/min and at pressures <5 psig.

6. Lastly, for real-time monitoring, open the bleeder valve on the upstream side of the reducer, so that the sampling whip is audibly purged during monitoring. This purging is required because of the considerable dead space gas volume in the sampling whip (e.g., ~20 mL air/ATA) and that of other upstream hardware — and the low reducer flow of ~150 mL/min.

7. Skip down to **DIVING AIR MONITORING** (**section F**).

E. TESTING SCUBA BOTTLES (previously charged) or TESTING LWDS AND FADS (during or following charging)

1a. To sample air from a <u>scuba bottle previously charged</u>, attach the scuba adaptor to the bottle, the adaptor allowing the HP sampling whip from the sampling kit to be attached to the bottle.

1b. <u>To sample the LWDS and FADS during charging</u>, blow out the charging whip with at least 10 times the estimated dead space volume of gas upstream from the actual air source at a highly audible rate to equilibrate the line with the gas. Shut off the flow when purging has been completed. Then attach the LWDS or FADS sampling adaptor, to which is then attached the charging whip.

1c. <u>To sample the previously charged LWDS and FADS</u>, blow out air through the site where the sampling adaptor will be attached to the LWDS or FADS: Do so at a highly audible rate, to equilibrate the line with gas of at least 10 times the estimated dead space volume of that gas upstream from the actual air source. Shut off the flow when purging has been completed. Then attach the LWDS or FADS sampling adaptor and leave the adaptor's charging connection plugged.

2. Attach one end of the HP sampling whip from the air sampling kit to the A/N fitting of the sampling adaptor.

3. With gas from the scuba bottle, LWDS, or FADS, blow out the HP sampling whip for 10 seconds. Then shut off the gas and, WITHOUT the Teflon tubing attached to the reducer, attach the other end of the HP whip to the reducer. Ensure the bleeder valve on the reducer is closed.

4. Open the appropriate valve(s) to deliver sample air to the reducer, and use “snoop” to check all connections for leaks, especially at both ends of the sampling whip. Correct any significant leaks. The reducer should deliver sample gas to the monitor at ~150 mL/min and at pressures <5 psig.

5. Lastly, for real-time monitoring, open the bleeder valve on the upstream side of the reducer so that the sampling whip is audibly purging during monitoring. This purging is required because of the low reducer flow (~150 mL/min) and the considerable dead space gas volume in the sampling whip (e.g., ~20 mL air/ATA) and in the other upstream hardware.

6. Continue with the procedures in **DIVING AIR MONITORING** (**section F**).

F. DIVING AIR MONITORING

1. Turn the monitor pump OFF by pressing “5”, and then attach the Teflon tubing to the reducer and **record** the time that the monitor has been attached.

2. Before the monitor is attached to the reducer — but ONLY if alarm latching is desired (so that any triggered alarms will continue even when gas concentrations become acceptable) — latching will need to be reset to ON as follows:

1) Enter the passcode by pressing “1-menu;” then “0,” “1,” “0,” and “2;” followed by “0.” Then press “2–Alarm Settings.”

2) Confirm that the alarm latching is now OFF. If it is, change this setting by pressing “1,” so that if any alarms are triggered, they will stop once the gas concentrations are acceptable. Note that any alarm triggered in the latching mode has to be reset: Pressing the “f” key, followed by the code (0102), resets the alarm.

3) Press “0” two times to return to the monitoring screen.

3. **Record** the alarm latching status on the data sheet.

4. If desired, start the program (Peak Program) to collect the highest gas concentrations observed: hit “6–Start,” and **record** the start time. Hitting “6–Stop” (*do <u>not</u> do this now*) will show the peak readings since this program has started.

5. Allow air monitoring to proceed as needed, and **record** on the data sheet any procedures performed during the testing time. Also **record** any information relevant to the test: e.g., alarms going off, problems such as instrument malfunctions, or the presence of any objectionable odor in the sample gas.

6. **Record** gas readings and times as needed in the DATA / COMMENTS section of the data sheet or, if more room is needed, on the back of the sheet.

7. Before any changes or adjustments (e.g., changing out scuba bottles, or opening or closing upstream valves) are to be made to the HP air being delivered to the reducer, one precaution is recommended: To avoid possible hardware failure that could damage the air monitor, the Teflon tubing should be disconnected from the reducer. The monitor should be reconnected after these changes have been made.

8. When testing is completed (or when a display of peak gas concentrations is desired), hit “6–Stop” and **record** the peak values and time on the data sheet. Press “0” to return to the monitoring mode. Restart and restop the peak functions as desired, and **record** these data as needed.

9. Disconnect the Teflon tubing from the reducer; then shut off the flow of sample gas to the reducer, and use the reducer bleeder valve to depressurize it. To remove the sampling hardware from the compressor line, disconnect the HP whip at the sample site.

10. Finally, **record** the battery reading and turn off the monitor by pressing the red key. **Record** the turn-off time.

11. Remove the sampling hardware, including the sampling whip from the reducer, and remove the monitor from the sampling apparatus. After drying off all gear (if necessary), put all of it except the monitor back into the sampling kit, and, with the Teflon tubing CONNECTED to the reducer, return the kit to the storage area. Bag the open end of the Teflon tubing.

12. Take the monitor to a safe location and connect it to the battery charger.

13. After the battery has been recharged and until the monitor is needed again the next test day, the monitor can be left connected to the charger. OR, if the monitor is to be stored for no longer than two weeks, it can be repacked into the sampling kit with the monitor ATTACHED to the Teflon tubing, *after the battery has been confirmed to be fully charged*.

END OF DIVING AIR MONITORING PROCEDURES

G. AMBIENT AIR MONITORING

1. This procedure uses the air monitor alone, without the sampling kit hardware and with the monitor pump ON, to test suspect ambient air in the vicinity of a compressor. Such testing can evaluate (1) the possibility of contaminating the charging system by turning on the compressor and drawing in suspect air, and (2) the chemical safety of suspect ambient air that is being compressed and then used for diving.

2. After the monitor start-up and calibration procedures (**section C. MONITOR STARTUP AND CALIBRATION**) have been completed, leave both the monitor and the pump turned ON, and remove the monitor from the sampling apparatus.

3. **Complete** the top third of the second page of the data sheet: **Fill in** the appropriate information about the ambient air that is being sampled. If necessary, use the back of this data sheet to **record** additional comments related to testing.

4. Confirm that the pump is ON. On the appropriate line of the data sheet, **record** the time.

5. ONLY if alarm latching is desired (so that any triggered alarms will continue even when gas concentrations become acceptable), latching will need to be reset to ON as follows:

1) Enter the passcode by pressing "1-menu," then "0," "1," "0," and "2", followed by "0." Then press "2–Alarm Settings."

2) Confirm that the alarm latching is now OFF; if so, change this setting by pressing "1," so that if any alarms are triggered, they will stop once the gas concentrations are acceptable. Note that any alarm triggered in the latching mode will have to be reset: To do so, press the "f" key, followed by the code (0102).

3) Press "0" two times to return to the monitoring screen.

6. **Record** the alarm latching status on the data sheet.

7. If desired, start the program (Peak Program) to collect the highest gas concentrations observed: Enter "6–Start," and **record** the start time. Entering "6–Stop" (*do <u>not</u> do this now*) will show the peak readings since this program was started.

8. The monitor can now be moved about to sample the ambient air. But, to avoid contaminating the air being drawn into the monitor by the pump, the user should avoid breathing near the monitor's inlet. To produce reliable readings, wait at each sampling location for at least 5 min to allow readings to stabilize: Such readings are best achieved by setting the monitor down at each location where the atmosphere is to be monitored and, while waiting for equilibration, viewing the gas readings at a distance.

9. **Record** the needed gas readings, locations, and times in the DATA / COMMENTS section of the data sheet or, if more room is needed, on the back of the sheet.

10. Also **record** any procedures performed during the testing time, as well as any test-related information such as alarms going off, instrument malfunction problems, or the presence of any objectionable odor in the ambient air.

11. When testing is finished (or when desired), hit “6–Stop” to display the peak gas concentrations, and **record** the peak values and time on the data sheet. Press “0” to return to the monitoring mode. Restart and restop the peak function as desired, and **record** as needed.

12. Finally, **record** the battery reading, and turn off the monitor by pressing the red key. **Record** the turn-off time.

13. Dry off (if necessary) all gear. Then, with the Teflon tubing CONNECTED to the reducer, put all the gear except the monitor back into the sampling kit, and return the kit to the storage area. Bag the open end of the Teflon tubing.

14. Transport the monitor to a safe location, and connect it to the battery charger.

15. After the battery has been recharged and until the monitor is needed again the next test day, the monitor can be left connected to the charger. <u>OR</u>, if the monitor is to be stored for no longer than two weeks, it can be repacked into the sampling kit with the monitor ATTACHED to the Teflon tubing, *after the battery has been confirmed to be fully charged*.

END OF AMBIENT AIR MONITORING PROCEDURES

AIR SAMPLING DATA SHEET — Page 1 (of 2)
(version 1.0 OP-ASK)

Monitor Startup and Calibration

Date ___________ Facility _______________________ Person(s) Testing ___________________________

Air Monitor S/N (e.g., 315) _________________ Air Sampling Kit S/N (e.g., 12) _____________

Time Monitor (and Pump) Started _________ Battery Reading post 5 min (Reading/Time) ______% /________

<u>IF CALIBRATION WILL NOT BE DONE</u>, RECORD DATE OF LAST CALIBRATION (___________), ENSURE 20 MIN WARM-UP, AND SKIP TO PAGE 2.

CALIBRATION INFORMATION (<u>IF CALIBRATION DONE</u>)						
GAS CYLINDER INFORMATION			**SPAN GAS CONCENTRATIONS**			
	N_2	Span Gas	O_2 (%) (XX.X)	CO_2 (ppm) (XXXX)	CO (ppm) (XXX)	Isobutylene (ppm) (XX.X)
S/N						
Completed (X): Alarm Settings______ Span Gas Settings_______						
N_2 Cylinder Pressure___________psig Span Gas Pressure____________psig						
Time Pump turned OFF ________________						

CALIBRATION (after 20 min warm-up) — gas readings taken when stable (after at least 5 min)					
	Time	O_2 (%)	CO_2 (ppm)	CO (ppm)	VOC (ppm)
N_2 readings, start gas time ______					
ZERO CHANNELS. If Rezeroing needed, also record SECOND time and SECOND Postzero readings.					
Postzero N_2	/	/	/	/	/
Span Gas readings, start gas time ______					
SPAN CHANNELS. If Respanning needed, also record SECOND time and SECOND Postspan readings.					
Postspan Gas	/	/	/	/	/
Check of Alarm function (Pass or Fail/Time) ________/___________					
Turn on Pump					

COMMENTS (problems, recal, etc.)	**Use back of sheet if necessary.**

AIR SAMPLING DATA SHEET — Page 2 (of 2)
(version 1.0 OP-ASK)

Air Testing

Date ___________ Facility _______________________ Person(s) Testing ___________________________

Air Monitor S/N (e.g., 315) _________________ Air Sampling Kit S/N (e.g., 12) _____________

Air Source (Compressor [Make & S/N], Air Bank or Flask, Scuba, FADS, LWDS, charging or not?; Ambient Air)

____

Sample Site Information (valve or fitting #; other) ____

Compressor or Air Source history (if applicable; recent trouble or service, if any) _________________________________

____

Weather conditions (if air sampling is done outside) ____

Use back of sheet for additional comments

AIR TESTING	
	Time
Ambient Air Monitoring ONLY: Confirm Monitor Pump is ON	
Compressor Testing ONLY: Start up Compressor	
If using Sampling Apparatus: Turn OFF Pump and then attach Teflon tubing to Reducer	
Alarm Latching (ON or OFF; as desired) _________	
Start Peak Program (as desired)	

<table>
<tr><td>DATA / COMMENTS
(procedures, events, problems, odor, etc.)

Post 30 min compressor operation</td><td colspan="5">Use back of sheet if necessary to record gas readings and comments:</td></tr>
<tr><td>At end of testing, or as desired, Stop Peak Program and Record Peak Values</td><td>Peak O_2 %</td><td>Peak CO_2 ppm</td><td>Peak CO ppm</td><td>Peak VOC ppm</td><td>Time</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="5">Final Battery Reading ____________%; then turn Monitor off.</td><td></td></tr>
</table>

APPENDIX B

PHOTOS OF THE NEDU AIR SAMPLING KIT
(version 1.0 ASK)

SINGLE STORAGE CASE HOLDING THE NEDU AIR SAMPLING KIT

NEDU AIR SAMPLING KIT, WHICH CAN BE WHEELED ABOUT

OPENED CASE DISPLAYING THE "SAMPLING APPARATUS" (NORMALLY REMOVED FROM THE CASE BEFORE CALIBRATION AND AIR SAMPLING)

SAMPLING APPARATUS FOLLOWING REMOVAL FROM STORAGE CASE, WITH NEW BLEEDER VALVE DIRECTLY UPSTREAM FROM THE REDUCER

STORAGE CASE AFTER THE SAMPLING APPARATUS HAS BEEN REMOVED, WITH THE PROTECTIVE FOAM COVER (ON TOP OF THE SAMPLING HARDWARE NORMALLY STORED IN THE BOTTOM OF THE CASE)

THE SAMPLING HARDWARE NORMALLY STORED IN THE BOTTOM OF THE CASE, AFTER THE FOAM COVER HAS BEEN REMOVED

THE SAMPLING HARDWARE NORMALLY STORED IN THE BOTTOM OF THE STORAGE CASE: AT RIGHT, (1) THE NEW GAUGE FOR MEASURING PRESSURES OF THE CALIBRATION CYLINDERS AND (2) THE TWO CGA CALIBRATION ADAPTORS, BOTH NOW WITH HANDWHEELS

UNSCREWING THE FOUR BOLTS FROM THE PLASTIC COVER SECURING THE AIR MONITOR, TO REMOVE IT FROM THE SAMPLING APPARATUS (EITHER WHILE THE APPARATUS IS IN THE STORAGE CASE OR HAS BEEN REMOVED FROM THE CASE)

REMOVAL OF THE COVER ON TOP OF THE AIR MONITOR, FOLLOWING REMOVAL OF ALL FOUR BOLTS

THE AIR MONITOR, WITH COVER REMOVED AND NOW READY FOR REMOVAL FROM THE SAMPLING APPARATUS

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APPENDIX C

NEW HARDWARE IN THE NEDU AIR SAMPLING KIT (VERSION 1.0 ASK)

(all prices are approximate and based on the most recent quotations)

1. Zero (N_2) and Span Gases in 6A cylinders (115 liters) from Airgas South, Atlanta, GA. Total cost for the two cylinders ~$355.

a. Ultra high-purity N_2, with CGA 580 valve. Part # NI UHP6A. Cost ~$50.

b. Certified standard, with CGA 590 valve, with nominal concentrations of 21% O_2, 1000 ppm CO_2, 20 ppm CO, and 10 ppm isobutylene, balance N_2. <u>This is the new span gas mixture used in this project</u>. Part # XO5NI78**C**6A13R3 ("C" indicates certified standard). Cost ~$305.

c. Primary standard, with CGA 590 valve, with nominal concentrations of 21% O_2, 1000 ppm CO_2, 20 ppm CO, and 10 ppm isobutylene, balance N_2. <u>This is a more accurate span gas mixture that warrants discussion</u>. Part # XO5 NI78**P**6A13R3 ("P" indicates primary standard). Cost ~$365.

2. Pressure gauge assembly. Total cost ~$71.

a. Pressure gauge from Wika Instruments, Huntington Beach, CA.
0–3000 psig pressure gauge with a ¼-inch stainless steel male NPT lower mount fitting. Part # 9768610, Type 23X.53. Cost ~$35.

b. Three connecting fittings from Alabama Fluid Technologies, Daphne, AL.
These fittings allow the pressure gauge to be connected to the CGA adaptor on the zero and span gas cylinders.

1) ¼-inch female NPT to ¼-inch male Swagelok union. Attaches to gauge. Part # SS-400-7-4. Cost ~$12.

2) ¼-inch female Swagelok to ¼-inch female A/N union. Attaches to item (1). Part # SS-400-A-4ANF. Cost ~$10.

3) ¼-inch A/N plug. Attaches to (2); used to seal gauge when not in use. Part # SS-4-AN-P. Cost ~$14.

3. Bleeder valve assembly (bleeder valve is upstream of the pressure reducer). Total cost ~$53.

a. Bleeder valve available from Amron, Vista, CA.
Upstream and downstream connections ¼-inch female NPT. Part # SA4306. Cost ~$36.

b. Swagelok fittings available from Alabama Fluid Technologies, Daphne, AL.

1) ⅛-inch male NPT to ¼-inch male NPT reducing union. Allows pressure reducer to be attached to downstream side of bleeder valve. Part # SS-4-HRN-2. Cost ~$6.

2) ¼-inch male NPT to ¼-inch male A/N union. Allows HP sampling whip to be attached to upstream side of bleeder valve. Part # SS-4-AN-1-4. Cost ~$11.

4. Handwheel with CGA 590 calibration adaptor. Component parts available from Western Enterprises, Westlake, OH.
Facilitates installation and removal of the span gas cylinder adaptor. Replaces CGA 590 calibration adaptor (without handwheel) that came with the original NAVSEA 00C air sampling kit.

a. CGA 590 handwheel (requires longer nipple than that which came with the original NAVSEA 00C kit). Part # WES693P. Cost ~$18.

b. 3½-inch nipple with Teflon seat. (Western Enterprises Web page incorrectly lists the nipple as 3 inches long.) Part # WES615-3T. Cost ~$9.

5. Pelican 1610 Protector Black Case available from Cases2Go (Roots International-Govt), Lutz, FL.
Used to house new NEDU air sampling kit. Cost ~$206.

APPENDIX D

SHIPPING PROCEDURES FOR THE NEDU AIR SAMPLING KIT

FEDEX shipment of Hazardous Materials (Hazmat): The compressed gas cylinders in the air sampling kit are classified as hazardous materials for shipment.

1. Have a member of your command (Supply Department, etc.) who has a FEDEX account prepare a purchase order (PO) for shipment via FEDEX.

2. Also prepare a DD 1149 (Requisition and Invoice Shipping Document) for each Pelican case (each air sampling kit is contained in a single Pelican case).

3. Weigh each Pelican case: FEDEX requires the weight of each Pelican case that is being shipped to be entered on the FEDEX shipping request form.

4. Once the PO is ready, the FEDEX account holder should prepare a FEDEX shipping label for each Pelican case.

5. **THIS IS VERY IMPORTANT:** Check the Hazmat box on the FEDEX shipping form. Failure to do so will generate more work for the Hazmat shipper.

6. Your Supply/Shipping Department should know who is qualified to ship Hazmat. If you have questions about who this may be, contact the Base's Supply/Shipping Department. Take the Pelican cases and the completed forms to the Hazmat shipper.

7. The Hazmat shipper will prepare a Shipper's Declaration for Dangerous Goods Form and any additional forms needed for each Pelican case. The Hazmat office will provide the necessary stickers to be placed on each Pelican case.

8. The hazardous items (e.g., compressed gases) in each Pelican case will require material safety data sheets (MSDSs); these MSDSs are located in a pouch inside the top lid of the Pelican case (behind the foam).

9. When the kit has been submitted to FEDEX, FEDEX will check each shipment for the appropriate forms and stickers.